South Florida Water Management District

April 2000

Caloosahatchee Water Management Plan Appendices

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Appendix A
ECONOMIC ANALYSIS: CALOOSAHATCHEE ESTUARY RESOURCES

W. Daltry
Southwest Florida Regional Planning Council

METHODOLOGICAL ASSUMPTIONS

The Predicate

This assessment is being performed in conjunction with the *Caloosahatchee Water Management Plan* (CWMP). Consequently, the essential component of this analysis is to analyze the importance of freshwater flow into the tidal zone, which is described as the Caloosahatchee Estuary, in experienced economic terms and values. These activities and values are dependent upon the continuation of estuarine functions. These functions include: serving as a fish nursery and shellfish grounds, and serving as a habitat for aquatic and avian life, which consumes the living harvest, produced by the estuary.

Other economic activities, such as waterfront port activity, or some types of boating activity (such as sailing), that do not depend upon estuarine conditions, are excluded from this analysis. Consequently, high valued property with waterfront view would not be included in this analysis, although such properties would be included in an analysis of the value of quality environmental features.

The Locale

The Caloosahatchee Estuary is defined by the plume of reduced salinity that issues from the mouth of the Caloosahatchee River at the Franklin Locks, as well as some of the tributaries (Orange River, Whiskey Creek, Hancock Creek, etc.) that issue into the river west of the controlled mouth at the locks. This plume extends into San Carlos Bay, Pine Island Sound, lower Matlacha Pass, and upper Estero Bay, until its impact is attenuated into normal background conditions, or it is supplemented to an indistinguishable degree by the flows of smaller tributaries for these bodies, or it meets the flows of the Peace River in southern Charlotte Harbor. The Caloosahatchee River is the major freshwater body producing an estuary within Lee County.

The Assumption

Most data useful for an estuarine study is gathered at a county level, with smaller areas usually not capable for disaggregation due to propriety sensitive information. Consequently, information about Lee County will form the assumptions about the

Caloosahatchee Estuary, as factored by reasonable attempts to exclude information that may come from Boca Grande, or the Lower Estero Bay-Estero River/Imperial River Basin influence area.

Economic Value Categories

Direct and Sole. The primary economic statistics for economic value come from fishing statistics: licenses, landings, and employment in fishing and in fish processing. Using this information provides an estimate of direct values related to the estuary. Since most fish stocks are mobile, the assumption that is being made that fish landed in Lee County originated because of the Lee Estuary. These values are the primary direct economic impact of the estuary, but are not the total. It should be noted that multipliers are often used to assess further impacts; this report only uses one multiplier and that is for the direct value of seafood moving through the market place. These direct impacts include the obvious transactions that are directly related to each other. For example, the fishing boat captain that sells the haul pays the crew with part of the proceeds has performed two transactions with the same money, and both transactions are directly relevant for this analysis.

Shared. There are other activities that occur that depend in part upon estuary production and in part on other factors. Boat sales and marina activities are examples, where sometimes boats are used for sport fishing (estuarine production) and sometimes for some other purpose. An assumption will be made to reflect some degree of such activity being an economic value of the estuary, and such values will be included in the total assessment.

Indirect/Quality of Life. Finally, there are quality of life issues that the estuary provides, that are not easily expressed in measurable economic terms. For example, the endangered Florida manatee frequents the Caloosahatchee Estuary, and the threatened American eagle feeds within the estuary waters. Both species dominate ecotourism tours, and existing residents often associate sightings with their quality of life property value. Housing with bay/estuary views command high prices. However, the water supply plan is not likely to result in changes in these values, so any assumptions of value derived from these quality of life items are largely for discussion purposes.

Direct/Indirect/Induced. These are terms in common usage in economic value appraisals. One such study, *Estimated Economic Value of Resources* (Charolotte Harbor National Estuary Program, 1998) used these categories in preparing an estimate for the Charlotte Harbor watershed. The indirect and induced categories are not being used in this appraisal of the Caloosahatchee Estuary, primarily because such factors rely heavily upon modeling assumptions tied to regional input-output assessments. Since the economic values of an estuary can be fairly narrowly defined, such additional appraisals add uncertainty to the analysis that already has to heavily depend upon state or national information sources. The analysis of direct impacts should be pervasive enough to understand the value of the estuary and the relationship of its freshwater sources.

ECONOMIC ACTIVITY - DIRECT

Tourism

Estimated Economic Value of Resources (Charlotte Harbor National Estuary Program, 1998), provides some estimate of economic values for the overall harbor complex, of which the Caloosahatchee River is a part. Summarizing this report for Lee County, total tourism expenditures in 1996 were $1,207,490,480 or $58.75 per person per day. These expenditures were generally tied to living expenses, not the estuary, unless the person was there for fishing or nature study. Saltwater fishing (boat) for tourists in 1995 was an estimated 744,349 occasions overall, while Saltwater fishing (nonboat) was 288,185 occasions; nature study by tourists totaled 332,727 occasions, of which 50 percent were of the estuarine environment. If each occasion was equivalent to a half day, the total economic value of tourism tied to the estuary is $36,526,035. For a comparable statistic, saltwater fishing licenses for fiscal year (FY) 1997-98 for nonresidents totaled 30,840, with a license sale income of $485,000.

Resident Recreation

The same report provided for residential recreational activity. Saltwater fishing by boat totaled 72,818 occasions, and nonboat saltwater fishing provided 24,487 occasions, and nature study provided 179,144 occasions, which, if half were of the estuarine environment, would be 89,577 occasions. Applying one-half of the average estimated per capita disposable income at a daily basis for Lee County ($28.36) (University of Florida, 1997) yields a total $5,299,973 of residential recreational economic value tied directly to the estuary. For a comparable statistic, saltwater fishing licenses for residents for FY 1997-98 totaled 22,215, with a license fee income of $300,000.

Commercial Fishing

The same report provides estimates for commercial fishing activity within Lee County for 1996. For that year, 11,724,498 pounds of seafood (all varieties of seafood such as finfish, shrimp, crabs, lobster) were landed for a total direct sale price of $19,147,104. This volume made Lee County the fourth largest county source of seafood in volume and dollar value in Florida.

The landing of seafood and its sale results in direct multiplication of impact taking place as expenses, such as wages paid to the commercial fishermen, are met and food processors take the landings into the next stage of production. An accurate estimate for multipliers is difficult, particularly since the impact is felt within other reporting industries. Additionally, since fishing is part of the county's economic base, its impact will not necessarily be felt within Lee County since resale prices elsewhere, and the associated business structures and employment will be higher than direct sales prices here.

For an estimate of expenses paid to other entities, an early report *Costs and Returns in Commercial Fishing*, (Anderson et al., undated) was used. This report indicated that operational expenses approximated 48 percent of returns, with wages approximated at 31 percent. The cost of money (loans, etc.) was an additional 19 percent of receipts. These estimates would indicate that of the $19 million referenced above, $9.2 million returned to the local economy in the form of crew wages, fuel sales, waste disposal, supplies, repairs, and so forth. An additional $3.6 million went directly to financiers either locally or elsewhere to pay off long-term debt. Remaining receipts were disbursed between the captain and the owner, partly of which was spent locally.

A somewhat contradictory statistic comes from the Florida Statistical Abstract (FSA) estimates of direct employment in fishing in Lee County. According to the FSA, the fishing industry in Lee County involves an estimated 40 businesses (Table 10.37, FSA, 1997), with 180 employees, and an estimated annual payroll of $3.54 million. The contradiction lies partly in how the role of the captain, excludes a bonus system. The fiscal effect of the contradiction lies is calculating 31 percent of the receipts as expenses for crew ($5.9 million), as compared to FSA estimate of $3.54 million as payroll.

To estimate the impact of seafood entering the wholesale/retail and food service use markets, a multiplier of 2.5 was applied to direct sales prices in Lee County. This yielded an estimate of $47,867,760, or the price changed from approximately $1.63 a pound at the boat to $4.08 a pound retail (and higher at restaurants). For a comparison of multipliers, refer to *Economic Impact of Marine Recreational Boating on the Florida Economy, SGR-54* (Milon et al., 1983).

The summary of the fiscal impact of commercial fishing is as follows: initial receipts of $19,147,104; estimated expense disbursements of $12.8 million ($9.2 million operational expense and $3.6 million cost of money); and the additional transactions in the seafood of $47.9 million. The total value of these transactions is $79.8 million.

ECONOMIC ACTIVITY - SHARED

Boating

The volume of sales related to boating in 1995 totaled $103,800,171 (CHNEP, 1998), most receipts being sent elsewhere. According to *County Business Patterns* in 1995, sales of boats employed 275 persons in 45 firms with an annual payroll of $5,614, 000. Boat repair employed another 130 persons in 14 firms, with an annual payroll of $2,481,000. Boat storage (and marinas) employed another 196 persons in 22 firms, with a payroll of $3,637,000. Most receipts were sent out of the county.

To assess how much of the boating activity is due to the estuary, the percentage of boating activity ivolving recreational or commercial fishing must be determined. The *National Recreational Boating Needs Assessment Survey Final Report* (Hagler Bailley, Inc., 1997) indicates that 44 percent of recreational boaters engaged in fishing, but the survey did not state whether the boats were purchased solely for fishing. Consequently, this assessment only assumes that fishing is one half the motive for boat purchase for those who fish, which reduces the total from 44 percent to 22 percent. Applying this factor (22 percent) to the total payroll expenses of sales, repair, and storage of boats, results in $2,581,000 being the value of estuaries to employment in these three types of businesses. Applying the factor of 22 percent to total new boat sales results in $22,836,037 being spent as a result of estuaries. The resultant sum of these activities is $25,417,037.

SUBTOTAL - ECONOMIC ACTIVITY

The economic activity tied to the Caloosahatche Estuary is presented in **Table A-1**.

Table A-1. Economic Activity Related to the Caloosahatchee Estuary.

Activity	
Recreation-Tourist	$36,526,035
Recreation-Resident	$5,299,973
Commercial Fishing	$79,800,000
Boating	$25,417,037
Total for Lee County	$147,043,045

FACTORING FOR JUST THE CALOOSAHATCHEE BASINS ESTUARY

The calculations to this stage have been applied to Lee County as a whole. While the Caloosahatchee Estuary is the county's largest estuary, its estuarine zone does not encompass the entire county's estuary. To factor just for the Caloosahatchee Estuary, the impact area is presumed to be that defined by the presentation made by Dan Haunert (SFWMD) to the Caloosahatchee Advisory Committee (CAC) on January 21, 1999. This area did not include Boca Grande, Bokeelia, Burnt Store Marina, nor the middle to lower reaches of Estero Bay.

These areas described above contain 16 of the county's 61 marinas. Using a coarse assumption that the ratio of marinas outside the Caloosahatchee Estuary influence area reflects the percentage of activity summarized above as also being outside the area, a reduction factor can be estimated. This factor (26.2 percent) applied to the $147,043,045 figure subtotaled above, reduces the annual estimate of economic value directly associated with the Caloosahatchee Estuary to $108,517,760.

FACTORING FOR THE LIFE OF THE PLAN

The U.S. Army Corps of Engineers (USACE) and the SFWMD have recently completed the *Central and Southern Project Comprehensive Review Study* (Restudy) (USACE and SFWMD, 1995). The Restudy recommended changes in the timing and volume of releases from Lake Okkechobee. The CWMP is attempting to realistically appraise current and future water supply demands on the river and the minimum flow of the river necessary to maintain environmental values, which extend upon estuarine economic values. This economic analysis is oriented towards estimating for the CWMP the economic values of the current estuary. One test of the Restudy and the CWMP is whether it will act to improve or harm these values.

The Restudy is being refined and imlemented in the CERP. The target year to have all of the projects completed is 2050. Using that same target year, and applying the annual economic value of the estuary over that 50 years (no adjustment for changes in net present value), the estuary's worth will be $5,425,888,00 (in 2050).

THE BOTTOM LINE

The direct annual value of the Caloosahatchee Estuary to the area economy is approximately $108 million. Actions that would adversely affect the estuary can add up to that amount of impact to the cost of any proposal. Using the 50-year horizon of the CERP, the cost (resource loss) value would be $5.4 billion.

REFERENCES

Bureau of Economic and Business Research. 1997. *1997 Florida Statistical Abstract*, University of Florida. 158 pp.

Hazen and Sawyer. 1998. *Estimated Economic Value of Resources*, prepared for the Charlotte Harbor National Estuary Program. vari. pag.

Bureau of the Census. 1997. *County Business Patterns 1995, Florida*. U.S. Department of Commerce, CBP/95-11. 163 pp.

Andersen, C.L. & R.H. Mc Nutt. n.d. *Costs and Returns in Commercial Fishing*, Marine Advisory Program. SUSF-SG-73-002.

Hagler Bailley, Inc. 1997. *National Recreational Boating Needs Assessment Survey*, prepared for the International Association of Fish and Wildlife Agencies. 116 pp.

USACE and SFWMD. 1999. *Central and Southern Florida Project Comprehensive Review Study*. USACE, Jacksonville District, Jacksonville, FL and SFWMD, West Palm Beach, FL.

Appendix B
ANALYSIS OF WATER AND NUTRIENT BUDGETS FOR THE CALOOSAHATCHEE BASIN - AN EVALUATION OF AVAILABLE HYDROLOGIC DATA FOR THE CALOOSAHATCHEE BASIN

E.G. Flaig, P. Srivastava, and J.C. Capece
South Florida Water Management District
Institute for Food and Agricultural Sciences University of Florida

SUMMARY

Hydrologic data were collected from the South Florida Water Management District (SFWMD), National Oceanic and Atmospheric Administration (NOAA), and United States Geological Survey (USGS) for the Caloosahatchee region. The SFWMD obtained all of the available data from the USGS through a cooperative data exchange agreement. Weather data were purchased by SFWMD from NOAA. Because the available weather station coverage is sparse, data were collected for sites outside the Caloosahatchee Basin to include weather stations and ground water wells that can be used to describe conditions within the basin.

The hydrologic data include weather, surface discharge, water use pumpage, and ground water stage. The weather data include rainfall, temperature, wind, solar radiation, evaporation, and humidity data where available. Complete weather data are available for three sites in the region: Clewiston, S-78, and Big Cypress Reservation. Long-term rainfall data are available from many sites in the basin. The data in this report are restricted to those sites that have more than 16 years on record or have hourly rainfall values. The long period of record is necessary for model simulation and the hourly data are necessary to develop the daily rainfall pattern.

Surface discharge data were obtained from the USGS through the SFWMD for the primary discharge structures on the canals of the Central and South Florida Flood Control Project. Discharge data were not available for selected private structures on the primary canals.

Ground water stage data were collected for the Surficial Aquifer System (SAS) and the Tamiami aquifer. This aquifer interacts directly with surface water and is necessary to understand surface discharge.

The hydrologic data are summarized in this report. The data are provided in several formats on the website (http:\\www.imok.ufl.edu). Although it was intended that

these data be developed into a relational database, there has been no agreement among the many potential users concerning the structure or content of the database, nor has there been agreement on the appropriate software. As a result, the data are provided in flat (ASCII) files and Excel spreadsheets.

INTRODUCTION

Water management in the Caloosahatchee Basin has become an important issue as demand for water by agriculture, the urban sector, and the environment have increased. The basin is undergoing rapid urban development and there is a greater need for water. At the same time, development and environmental needs on Florida's lower east coast may reduce the supplemental water available from Lake Okeechobee. Agriculture depends on water released from Lake Okeechobee for irrigation during the dry season. In the future, it will be necessary to fully utilize the available water in the Caloosahatchee Basin. This requires an assessment of the basin resources.

One of the important components of a basin assessment is the evaluation of available hydrologic data. These data are necessary for development of water and nutrient budgets for the basin. These data are also necessary for determining the impact of alternative land and water management practices on water use and runoff. The primary approach for evaluating alternative practices is through hydrologic simulation.

This report includes the results of the search for hydrologic data pertinent to the development of hydrologic models. Compilation of hydrologic data is necessary for calibration and utilization of hydrologic models and development of the water and nutrient budgets. These data include weather data, tributary discharge, Caloosahatchee River (C-43) discharge, ground water stage, and pumpage values for various structures in the basin. These data often exist as time series for varying periods of record. Only data available in digital form for long periods were collected. Hydrologic data with short periods of record are difficult to use in hydrologic analysis because they do not contain sufficient climatic variability with which to assess the impact of alternative management practices. If the data were available in digital form, they were not included in this report. Where possible, data includes the results from earlier studies.

DATA COLLECTION

Hydrologic data were collected through the SFWMD from NOAA, USGS, and water control districts (Chapter 298 special taxing districts). The SFWMD maintains many monitoring sites in the region. The SFWMD purchased rain, wind, and temperature data from NOAA selected stations in the Caloosahatchee Basin (Clewiston, Fort Myers, Punta Gorda, and Immokalee). The SFWMD also acquired monitoring data from USGS through a cooperative data exchange program. The SFWMD acquired rainfall data from selected water control districts through cooperative agreements or as part of special conditions on permits.

The set of primary parameter values and time series data necessary for hydrologic simulation were compiled into a simple database which is well-documented, and suitable for use on a personal computer or Unix system. Most of the data are maintained in flat-files (ASCII) for ease of conversion for selected computer programs. This type of database format will allow revisions to be made to the subbasin specific primary data as new data become available.

HYDROLOGIC DATA

Weather Data

Hourly Weather Data

Detailed weather information is necessary for developing good estimates of potential evapotranspiration, predicting crop growth, estimating insect vector dispersion, and predicting prone to freeze. Each of these data sets influence water and agrochemical use in the basin. Detailed weather data are necessary for development and calibration of evapotranspiration models. In particular, net radiation, relative humidity, and wind speed are necessary data. Unfortunately there are few sites in South Florida where detailed weather data have been collected over a long period of time (suitable for conducting long-term hydrologic simulations). There are complete data sets for West Palm Beach and Miami. There are no long-term records for Southwest Florida. The Systemwide Hydrologic Modeling Group (SFWMD) supplements those data with temperature and wind data from this area for predicting potential evapotranspiration within the Caloosahatchee Basin.

Weather data were obtained from the SFWMD for both SFWMD sites and NOAA sites. No other data were found. There were three sites with complete weather data in the region. Of these sites weather data were obtained for three sites (Clewiston Field Station, Big Cypress Reservation, and Ortona Locks). The data were collected at 15 minute intervals and recorded on CR-10 data loggers. Data collection at these sites began in 1992 and continues to present. The weather data collected at the selected stations are presented in **Table B-1** and data are presented in **Figures B-1** through **B-3**.

Hourly Rainfall

Several hydrologic simulation models require hourly rainfall in order to calculate daily runoff. The models are useful for simulating nutrient transport. Hourly rainfall is not commonly measured. It is only available at selected locations (West Palm Beach, Miami, and Okeechobee) for long periods of record. In the past, hourly rainfall was quantified by digitizing stripcharts from weighing raingages. This was time consuming and limited the amount and quality of available data. Recently, tipping bucket raingages have been connected to electronic data loggers which can provide an accurate rainfall record at high temporal resolution.

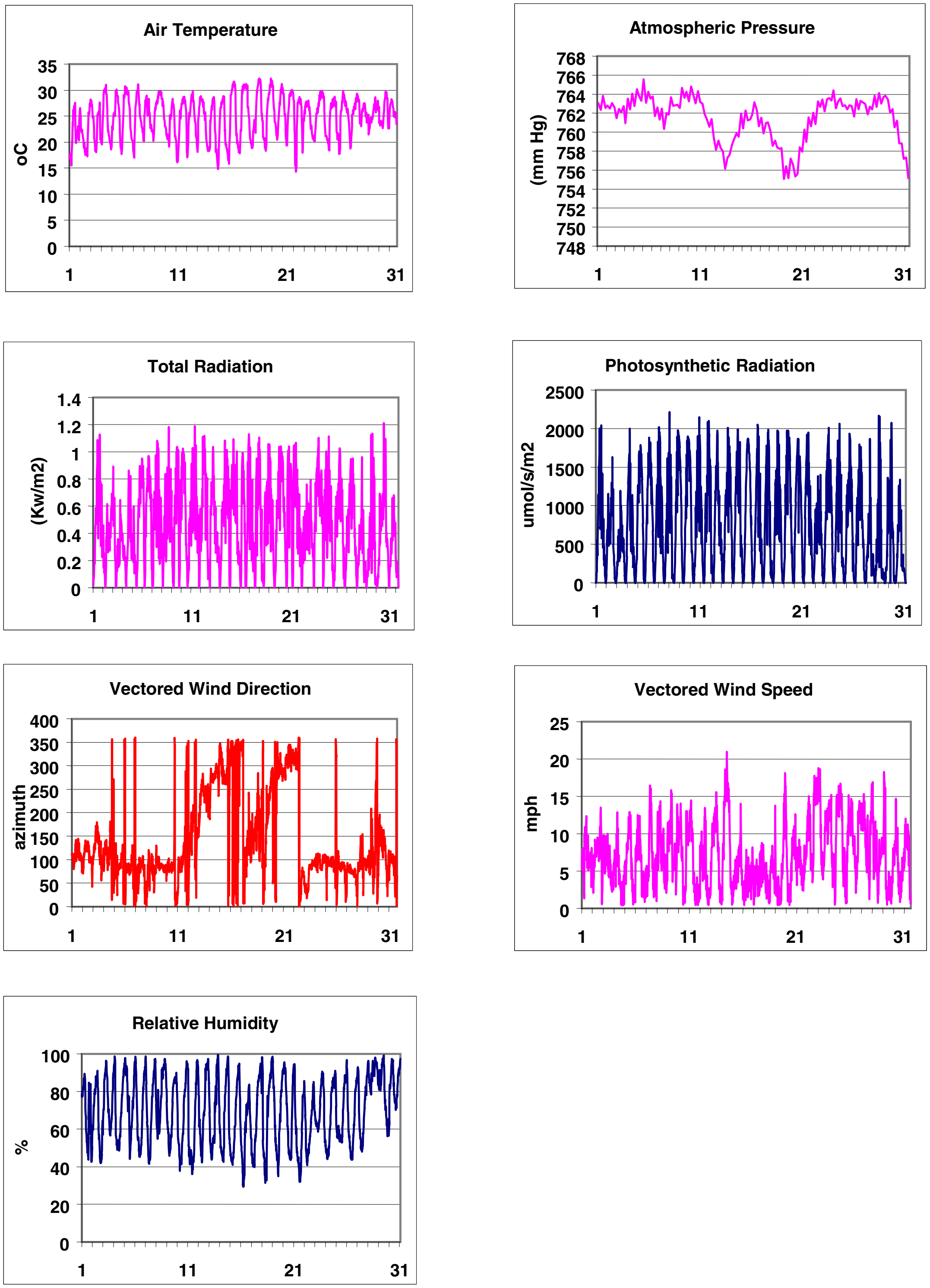

Figure B-1. Typical Hourly Weather Data, Ortona Locks (May 1993).

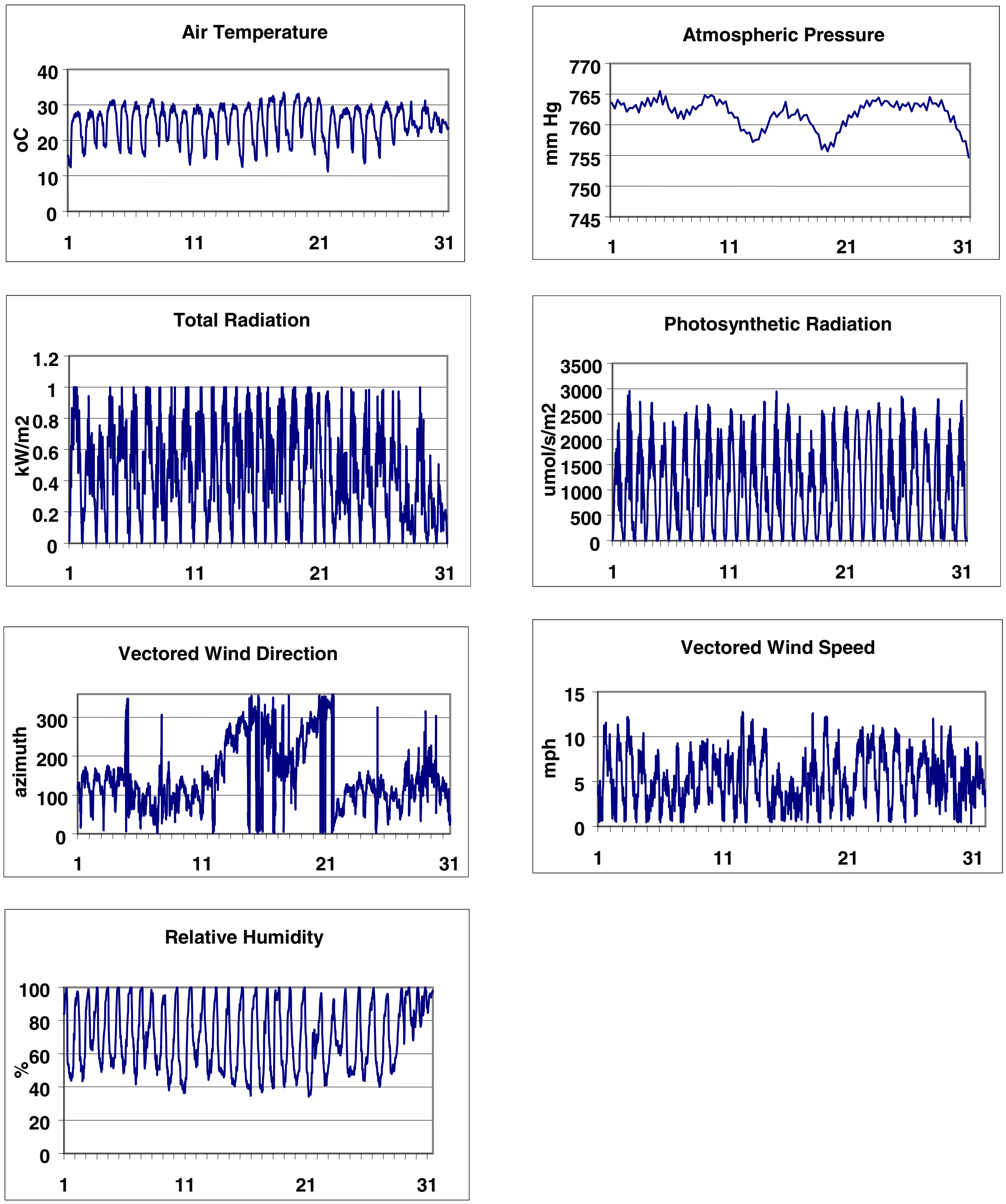

Figure B-2. Typical Hourly Weather Data, Big Cypress Reservation (May 1993).

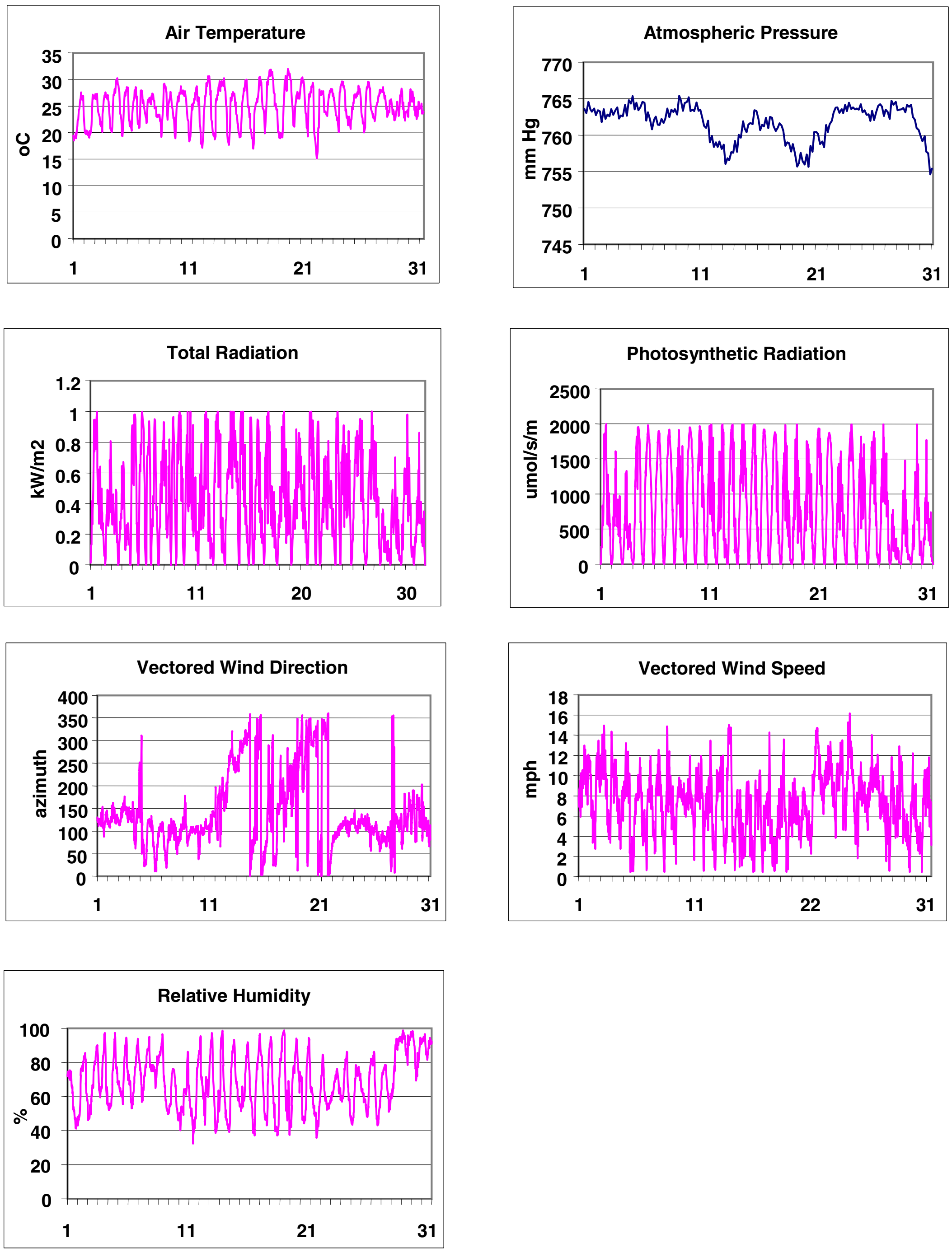

Figure B-3. Typical Hourly Weather Data, Clewiston Field Station (May 1993).

Table B-1. Weather Data for Selected Parameters in the Caloosahatchee Region.

Measurement	Equipment
Air Temperature (AT)	Vaisala HMP35C temperature and humidity probe
Relative Humidity (RH)	
Barometric Pressure (AP)	Vaisala PTA427 pressure transducer
Photo-active Radiation (RP)	LI-COR LI190SZ Quantum
Total Radiation (RT)	LI-COR LI1200SZ pyranometer
Vector Wind Speed (VS)	Qualimetrics Skyvane Model 2100
Vector Wind Direction (VD)	

There are six hourly rainfall gages in the Caloosahatchee region (**Figure B-4**). Data were available at these sites from 1992 to present (**Table B-2**). Typical data for these sites are presented in **Figure B-4** for May 1993. As indicated in **Figure B-4**, a substantial variability exists in rainfall within the basin. Hourly precipitation rates vary from 0.2 to 1.5 inches per hour (in. hr^{-1}) within a storm. There also is considerable difference in the rainfall pattern within a single storm among the stations.

Table B-2. Hourly Rainfall Sites for the Caloosahatchee Region.

Station	DBKEY	Start Date
Big Cypress Reservation	15685	10/21/92
Clewiston Field Station	15517	10/21/92
Lehigh Acres	15464	11/1/92
Palmdale	15786	4/16/92
S-78w	15495	10/21/92
Whidden Ranch	15465	11/9/92

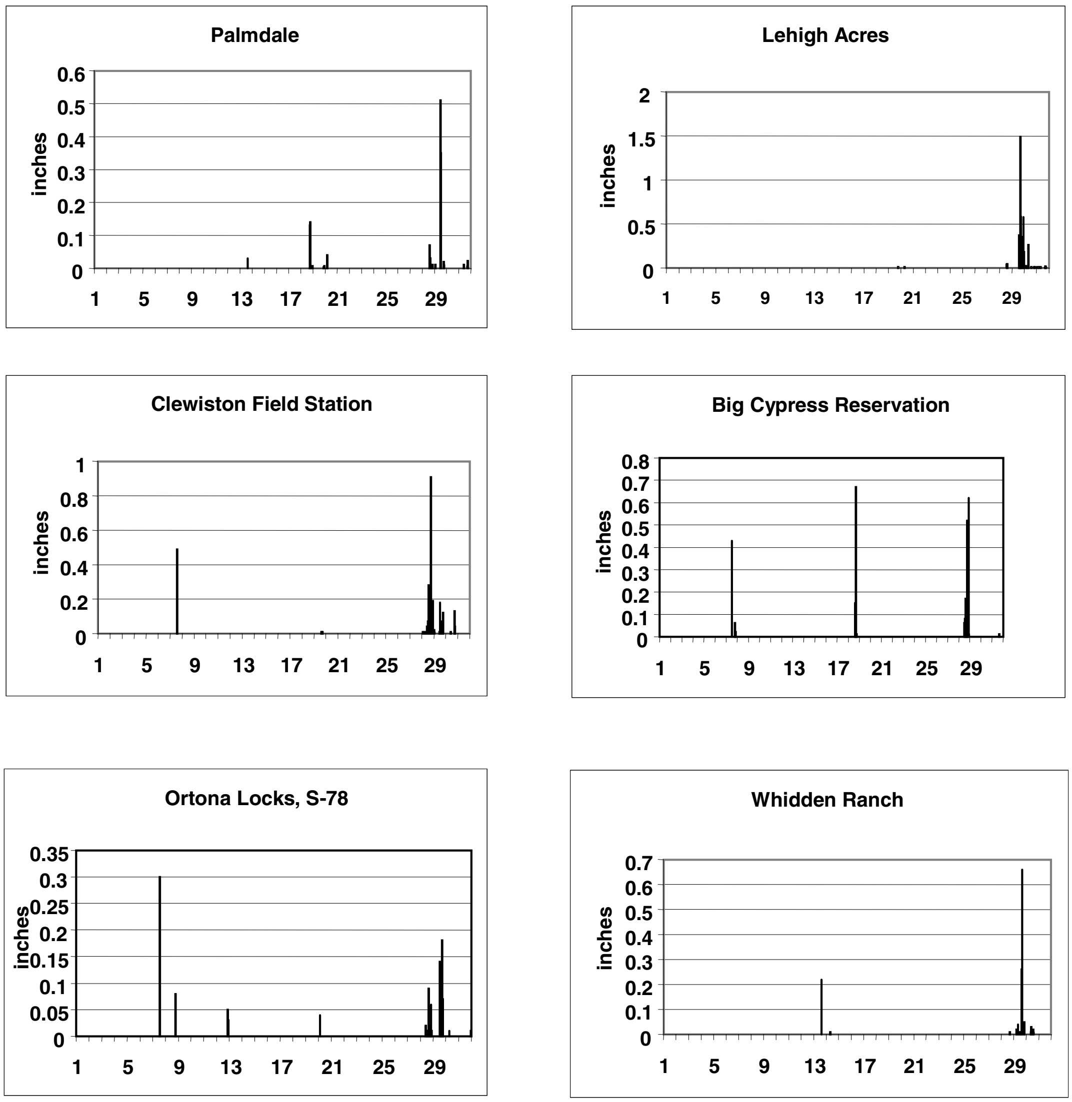

Figure B-4. Typical Hourly Rainfall Volume for the Caloosahatchee Region.

Long-Term Rainfall

Long-term rainfall data are necessary for conducting three analyses for basin assessment. The long-term data are used to develop the relationship between rainfall and runoff, and determine how that relationship may have changed following changes in land use. These data are necessary for hydrologic simulation; a short period of record may not provide a sufficiently varied data set for evaluating alternatives. Finally, the long-term data are used to evaluate the spatial variability in rainfall in the basin. The spatial variability in rainfall determines how the measured data from the monitoring network are combined to provide areal rainfall estimates.

Long-term daily rainfall volumes were collected for 15 locations. These data were collected by several agencies: NOAA, SFWMD, United States Army Corps of Engineers (USACE), and the Florida Department of Forestry (FS) (**Table B-3**). There is a range in length of record beginning with Fort Myers that began in 1909 to Whidden Ranch where collection began in 1982. At most sites, rainfall was collected in a standard can and measured in the morning. Two other sites, Lehigh Acres and Clewiston are not included in this list. At those sites, rainfall was recorded only on weekdays and does not present high quality data.

Typical daily rainfall records are presented for the period May to September 1993 in **Figures B-5a** and **B-5b**. Note the similarity in rainfall patterns at sites that are in close proximity such as S-79 and Fort Myers, compared to inland sites. Also note the variability in rainfall volume.

A set of Thiessen polygons was created to apply the rainfall data to the Caloosahatchee Basin. According to this scheme, all land within each polygon receives the rainfall record from that site. Alternatively, a universal kriging can be use to provide areal estimates of rainfall for each land use parcel. The disadvantage of kriging is that the extreme values in the data set are lost and replaced by areal average.

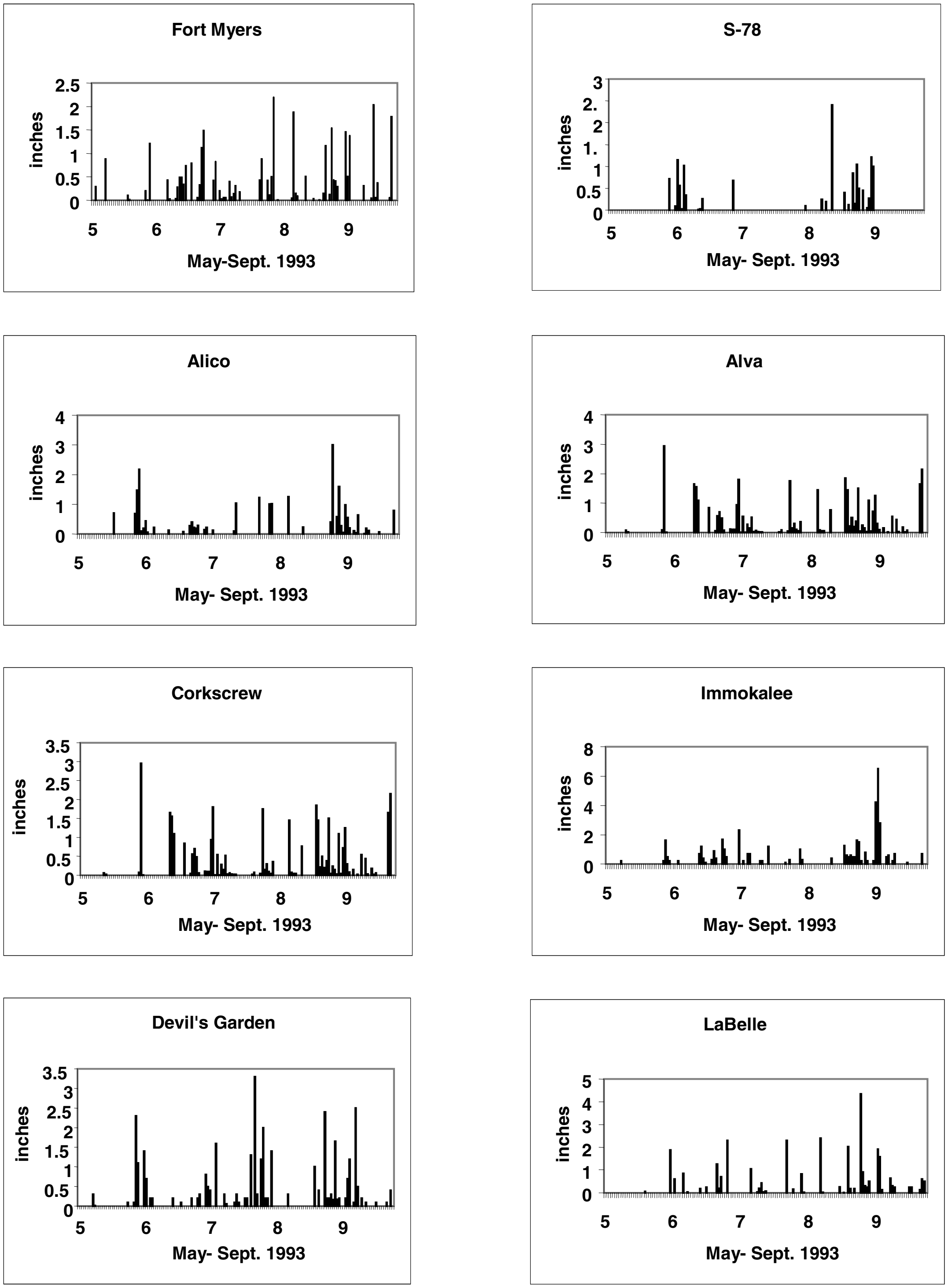

Figure B-5a. Typical Rainfall for Long-Term Raingages in the Caloosahatchee Region.

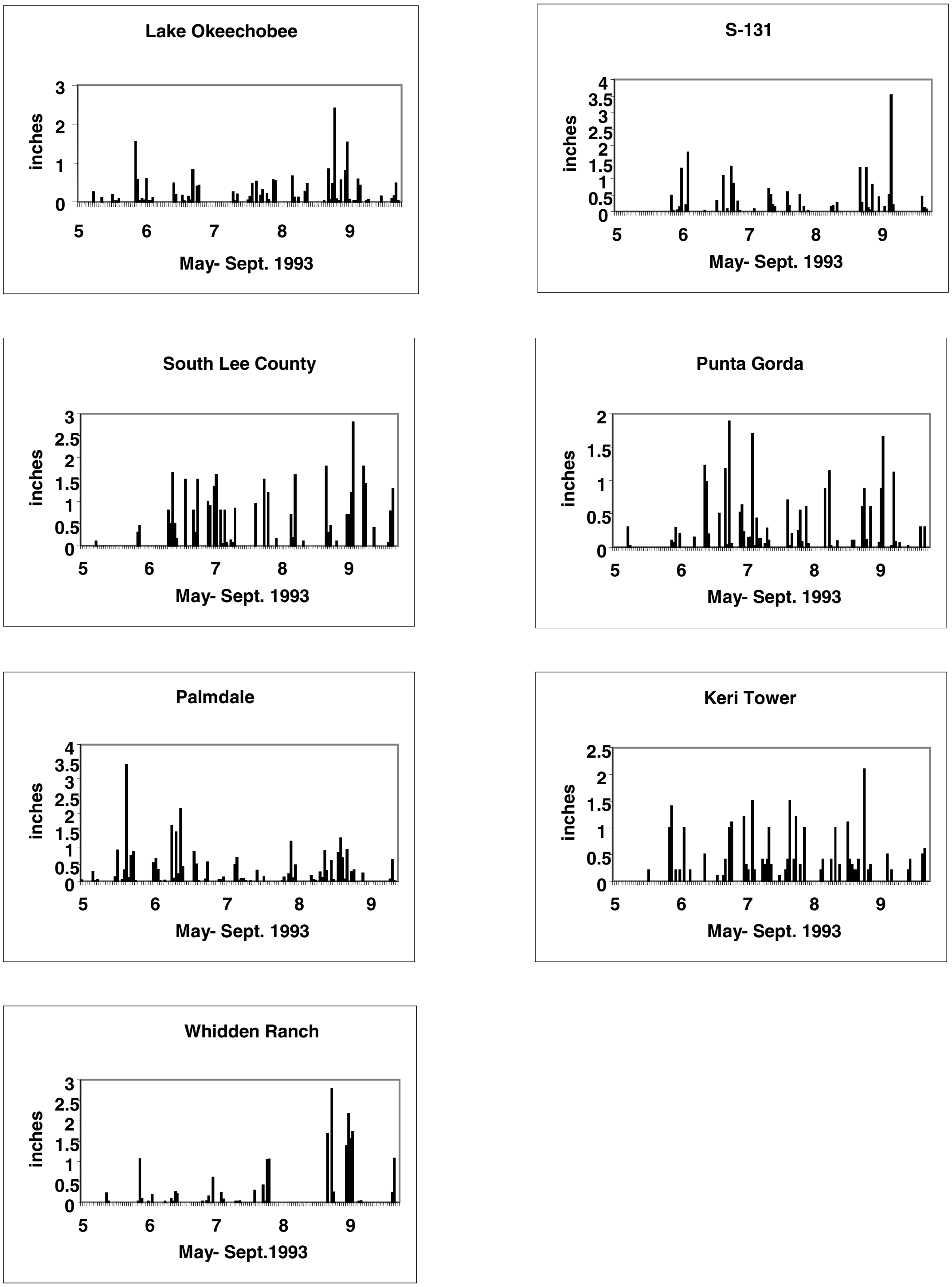

Figure B-5b. Typical Rainfall for Long-Term Raingages in the Caloosahatchee Region.

Table B-3. Long-Term Rainfall Data in the Caloosahatchee Region.

	Station Location	Station Name	DBKEY	Start Year	Source
1	Punta Gorda	PUNTA G4_R	06139	1965	NOAA
2	Alva	ALVA FAR	05922	1968	SFWMD
3	Corkscrew	CORK.HQ_R	05916	1959	SFWMD
4	Fort Myers	FORT MEY_R	06193	1909	NOAA
5	Immokalee	IMMOKA 2_R	06082	1963	FS
	Immokalee	IMMOKA 3_R	06195	1941	NOAA
6	South Lee County	SLEE_R	06081	1969	FS
7	Whidden Ranch	WHIDDEN3_R	06555	1982-1990	SFWMD
	Whidden Ranch	WHIDDEN3_R	15465	1992	SFWMD
8	S-131	S131_R	06120	1965	SFWMD
9	Lake Okeechobee	L OKEE.M_R	05883	1976	SFWMD
10	Devil's Garden	DEVILS_R	06206	1956	SFWMD
11	Alico	ALICO_R	15197	1973	SFWMD
12	Keri Tower	KERI TOW_R	06083	1969	FS
13	LaBelle	LA BELLE_R	06158	1929	NOAA
14	S-78	S78_R	06243	1940-1991	NOAA
	S-78	S78_R	16625	1991	SFWMD
	S-78	S78_R	06221	1968	USACE
15	Palmdale	PALMDALE_R	06093	1963	FS

FS- Florida Department of Forestry, NOAA- National Oceanic and Atmospheric Administration, SFWMD- South Florida Water Management District, USACE- United States Army Corps of Engineers.

Temperature

Temperature data are used for estimating evapotranspiration. Daily maximum and minimum temperatures were collected at nine stations in the region (**Figures B-6a** and **B-6b**). The District had data from 1931 for Moore Haven, Fort Myers, and Arcadia (**Table B-4**). Except for Immokalee which starts in 1970 and Archbold which starts in 1969, there is a complete set of data from 1965 to present. Typical values are presented for May 1993 (**Figures B-6a** and **B-6b**).

Table B-4. Minimum and Maximum Temperature Data for the Caloosahatchee Region.

	Station	Start Date
1	Punta Gorda	11/1/65
2	Moore Haven	1/2/31
3	LaBelle	7/1/48
4	Immokalee	6/1/70
5	Fort Myers	1/1/31
6	Devil’s Garden	6/1/56
7	Clewiston Field Station	11/1/49
8	Arcadia	1/1/31
9	Archbold	1/1/69

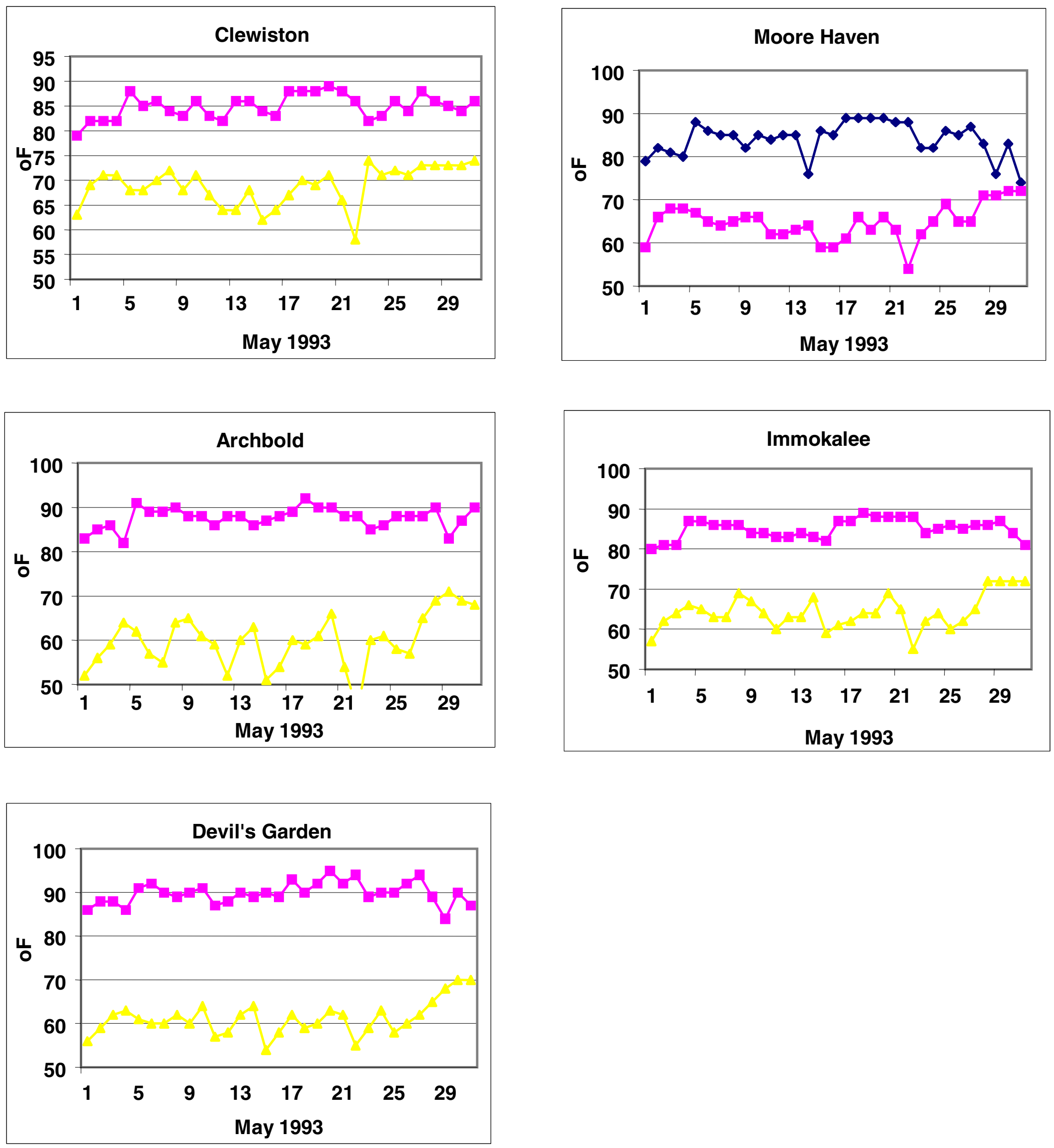

Figure B-6a. Typical Daily Minimum and Maximum Temperatures for the Caloosahatchee Region.

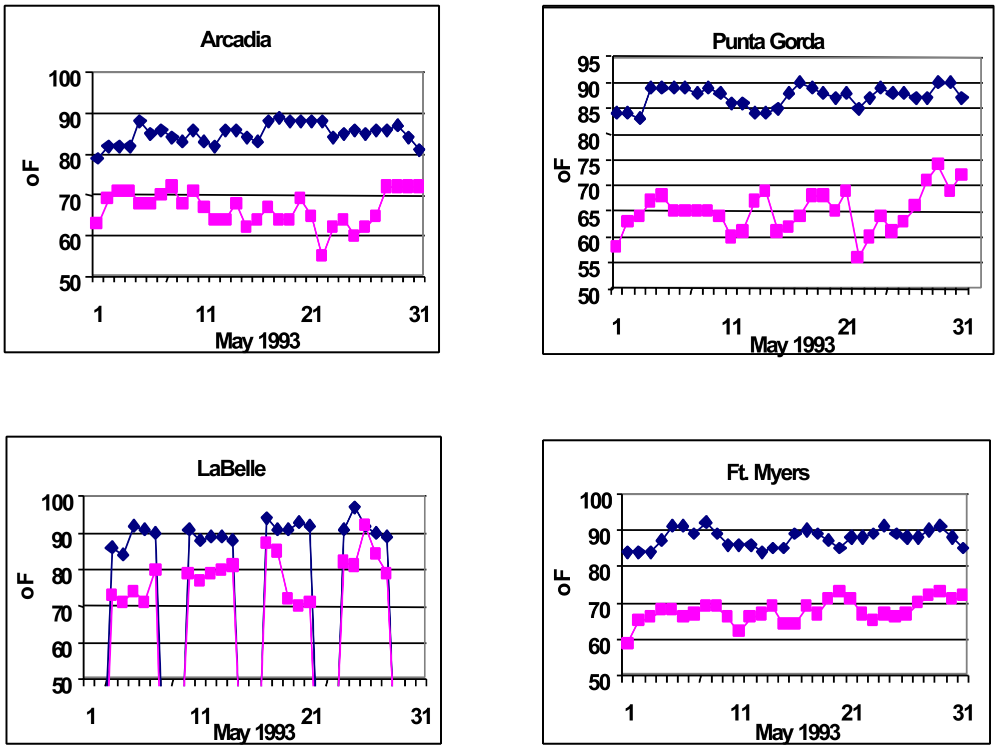

Figure B-6b. Typical Daily Minimum and Maximum Temperatures for the Caloosahatchee Region.

Evaporation Data

Where weather data are not available for estimating potential evapotranspiration (ET), evaporation pan values provide useful information. These data combined with crop coefficients provide reasonable ET estimates. Evaporation values were available at four sites in the basin (**Figure B-7**). At two of these sites, the data were collected by NOAA (Clewiston and HGSLE). At the other two sites (Clewiston Field Station and Lehigh Acres), the data were collected by SFWMD (**Table B-5**). These data are not current but they do present a period of record during a period of substantial land use change in the basin. Other data were collected at Corkscrew Sanctuary and Palmdale, but for shorter periods. The data from Lehigh Acres were collected only during weekdays so the Monday values are averaged across the weekend.

Table B-5. Evaporation Pan Data for the Caloosahatchee Region.

Station	DBKEY	Period of Record	Source
Clewiston	06365	1970-97	NOAA
Clewiston Field Station	15208	1983-90	SFWMD
HGSLE	06381	1948-97	NOAA
Lehigh Acres	06330	1978-90	SFWMD

NOAA- National Oceanic and Atmospheric Administration, SFWMD- South Florida Water Management District.

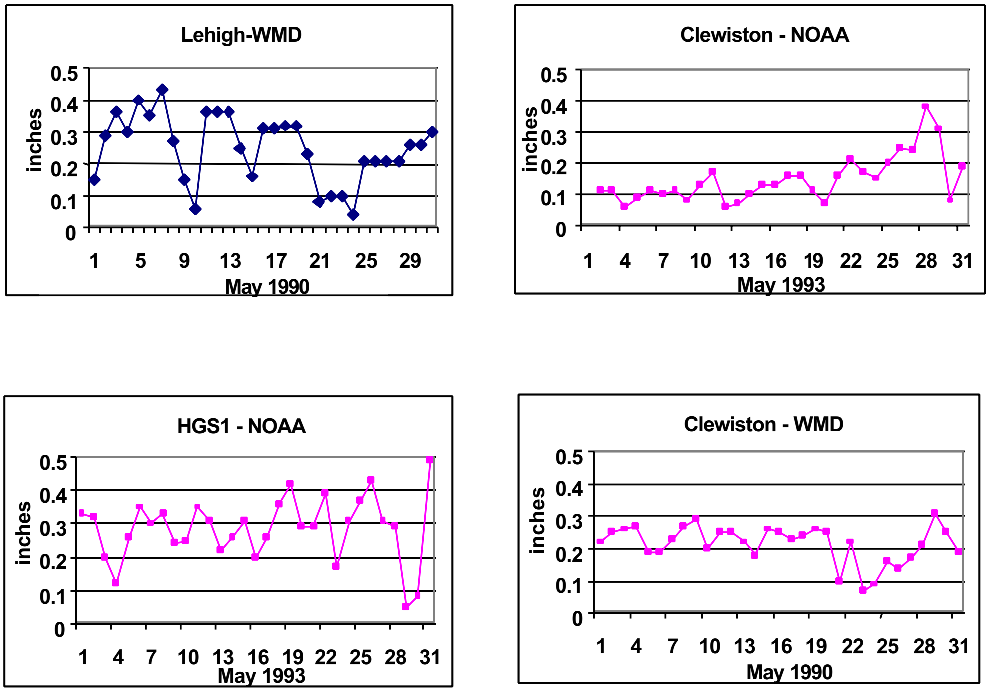

Figure B-7. Typical Daily Evaporation Pan Values for May.

Surface Water Discharge

Surface water is monitored at the primary structures on the Caloosahatchee River (C-43) and C-19 canals (**Figure B-8**). The C-43 structures include the lock and spillway structure at Lake Okeechobee (S-77), the gated culverts (S-235) that control water exchange between the East Caloosahatchee Basin and the S-4 Basin, the lock and spillway structure at Ortona (S-78), and the Franklin Lock and Dam Structure (S-79) at Olga. The structures on the C-19 Canal include S-47d at Lake Hicpochee, S-47b near highway US 27, and S-342 at the terminus in Nicodemus Slough. The flow data were calculated by the SFWMD and USGS based on USACE gate-opening data and upstream and downstream stages (**Table B-6**). The USGS data have been accepted as the preferred data sets at each structure. The quality of the discharge rating data is unknown, the USGS had intended to redevelop the stage-discharge curves for each structure. The total monthly discharge for each structure is presented in **Figure B-8** along with runoff. Runoff is defined as the discharge from S-79 minus the inflow from S-77, S-235, and S-47d. Runoff does not include any regulatory discharge from Lake Okeechobee.

Table B-6. Monitored Surface Water Discharge Structures in the Caloosahatchee Basin.

Structure	Description	DBKEY	Record	Source
S-77	Lock & Dam	00853	---	USGS*
		15016	1963 - 90	SFWMD
		15635	1972 - 97	SFWMD
S-235	Gated Culverts	04214	1975 - 90	SFWMD*
		15564	1990 - 97	SFWMD*
		12815	1988 - 97	SFWMD
S-47B	Gated Culverts	04326	1978 - 91	SFWMD
		15944	1995 - 97	SFWMD
S-47D	Spillway	04376	1975 - 93	SFWMD
		15578	1993 - 97	SFWMD
S-342	Culvert	13163	1992 - 97	SFWMD
S-78	Lock & Dam	00857	1971 - 97	USGS*
S-79	Lock & Dam	00865	1966 - 96	USGS*
		15045	1963 - 90	SFWMD

* Preferred data for analysis.

SFWMD- South Florida Water Management District, USGS- United States Geological Survey.

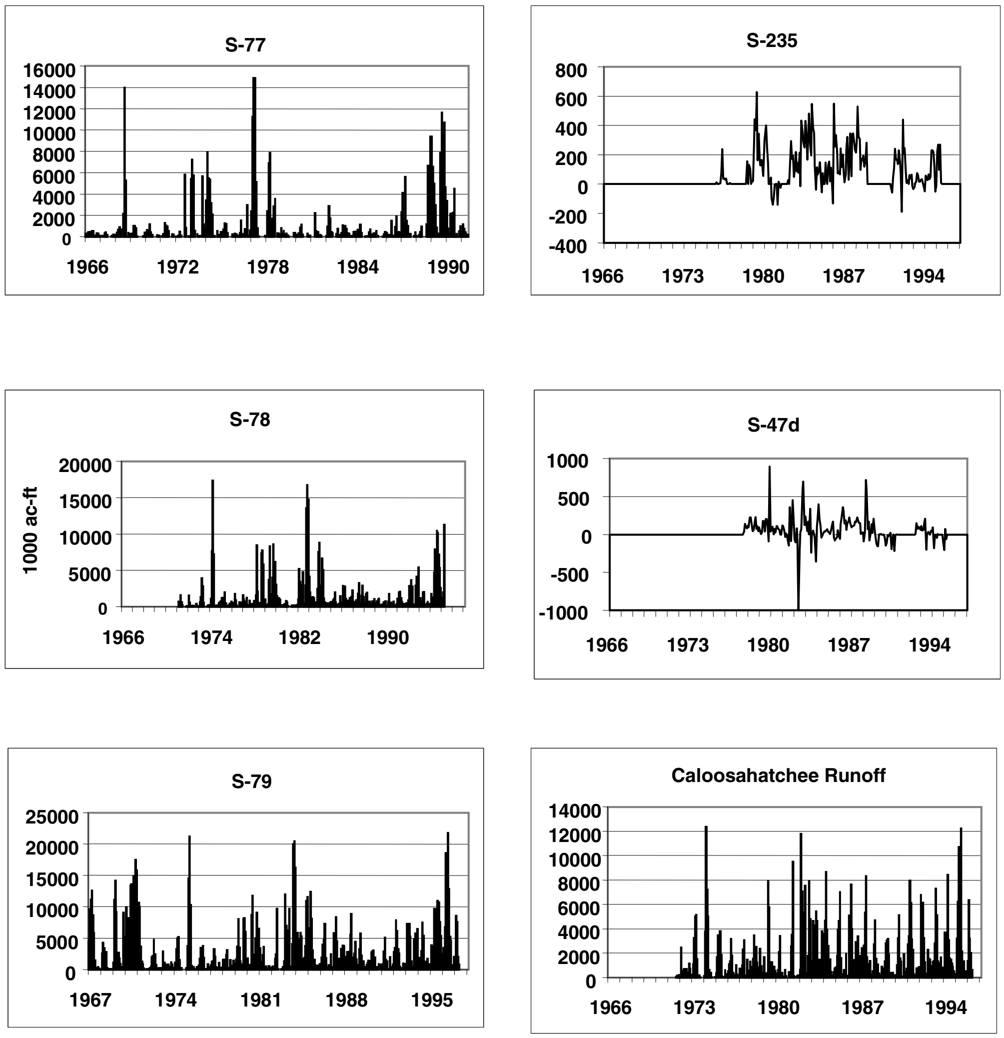

Figure B-8. Total Monthly Discharge and Runoff for Major C-43 Canal Structures.

Ground Water Stage

Ground water head information is useful for monitoring ground water usage and local recharge. Head data from the water table aquifer can be used to evaluate the effectiveness of seepage systems and alternative surface water management practices on local ground water storage. Unfortunately, there are few active wells in the basin.

There are many ground water monitoring wells in the Caloosahatchee Basin. The digital records for 72 ground water monitoring are available in the SFWMD database. These wells were used to monitor piezometric head in the water table, lower Tamiami, and Sandstone aquifers. Most of these wells were monitored in the 1970s and 1980s. There are 34 active ground water stage monitoring wells in the basin: 16 wells are in the west Caloosahatchee Basin, three wells are in the Orange River Basin, three wells are in Flagpole Basin, and 11 wells are in the East Caloosahatchee Basin (**Table B-7**). Several of the active wells are USGS wells. The typical head data for those wells are presented in **Figures B-9a** and **B-9b** for the May 1994. The remaining wells are part of the SFWMD ambient ground water monitoring program. The stage data for the period of record for those wells are presented in **Figures B-10a**, **B-10b**, **B-10c**, and **B-10d**.

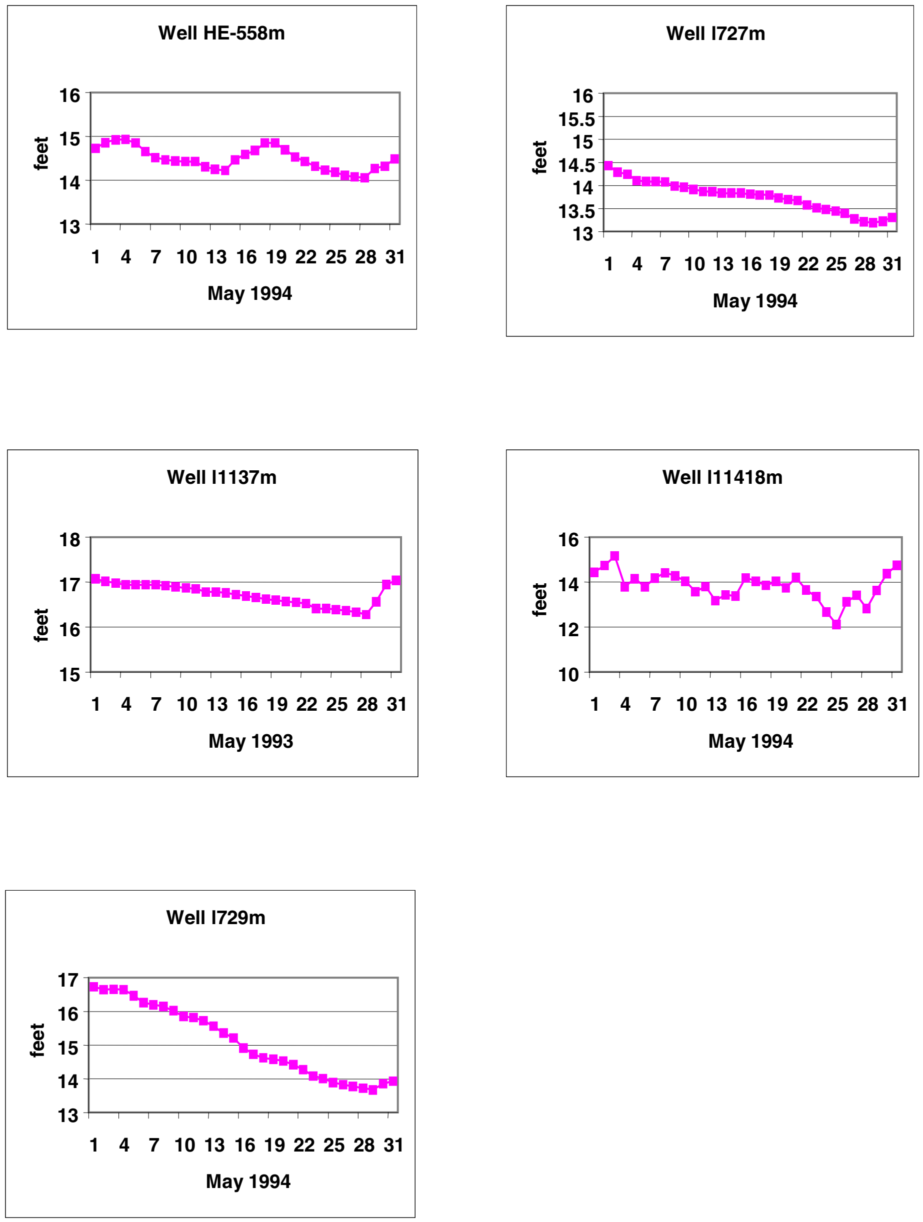

Figure B-9a. Typical Head Data from Shallow Ground Water Wells in the Caloosahatchee Basin (May 1994).

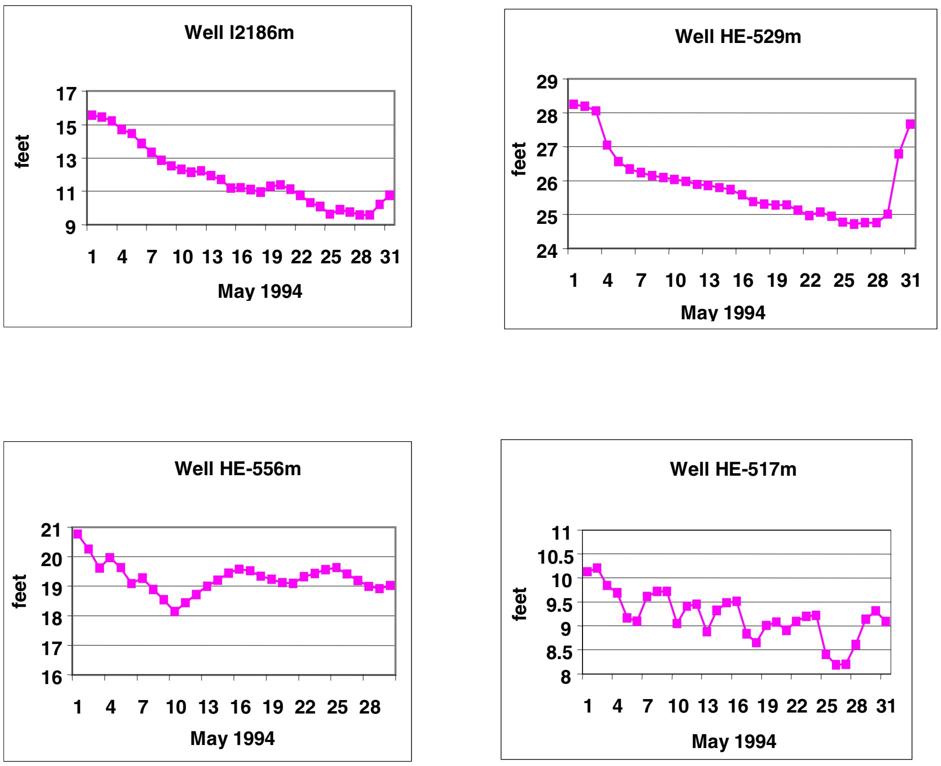

Figure B-9b. Typical Head Data from Deep Ground Water Wells in the Caloosahatchee Basin (May 1993).

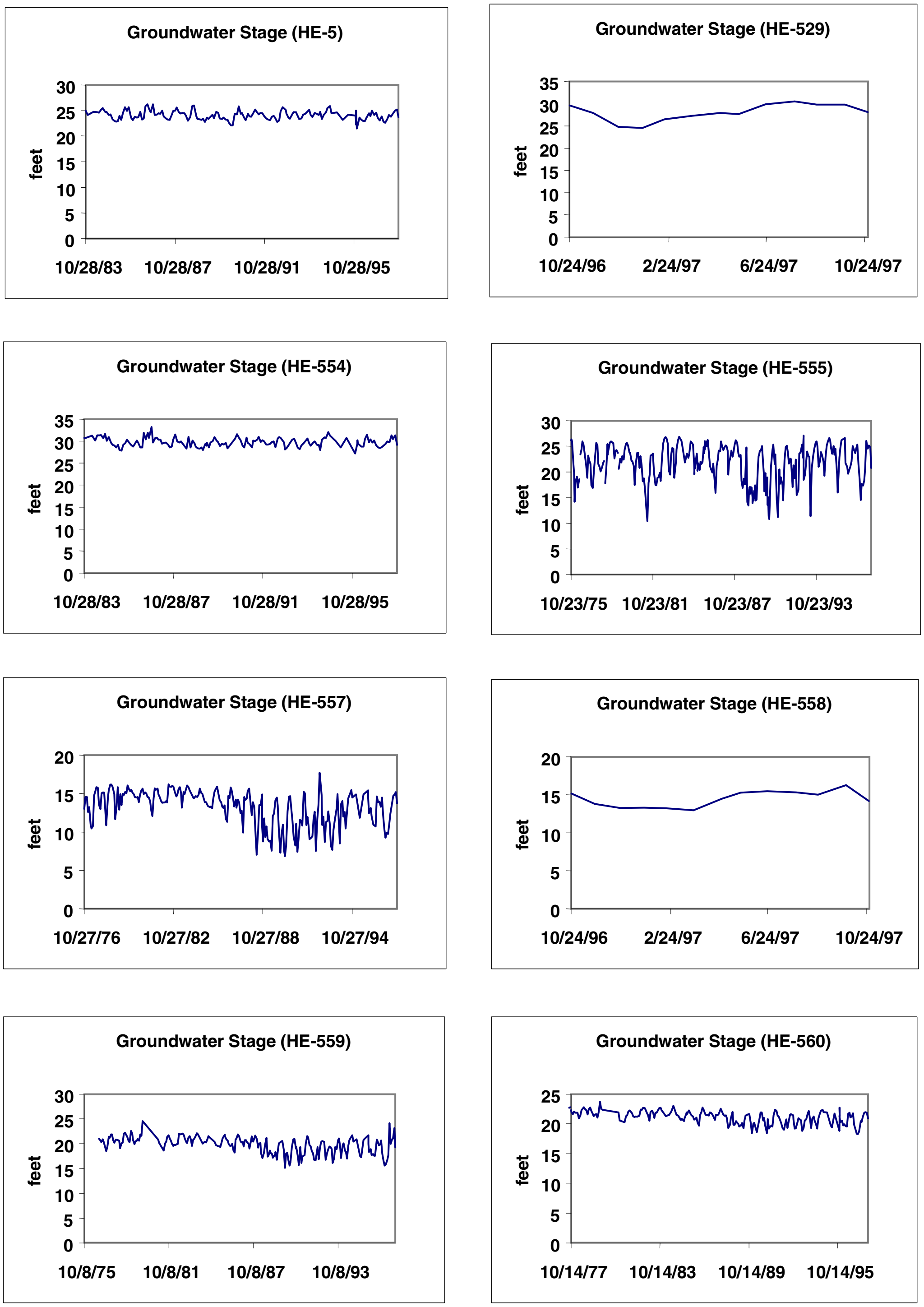

Figure B-10a. Ground Water Stage for Period of Record for SFWMD Ambient Monitor Wells.

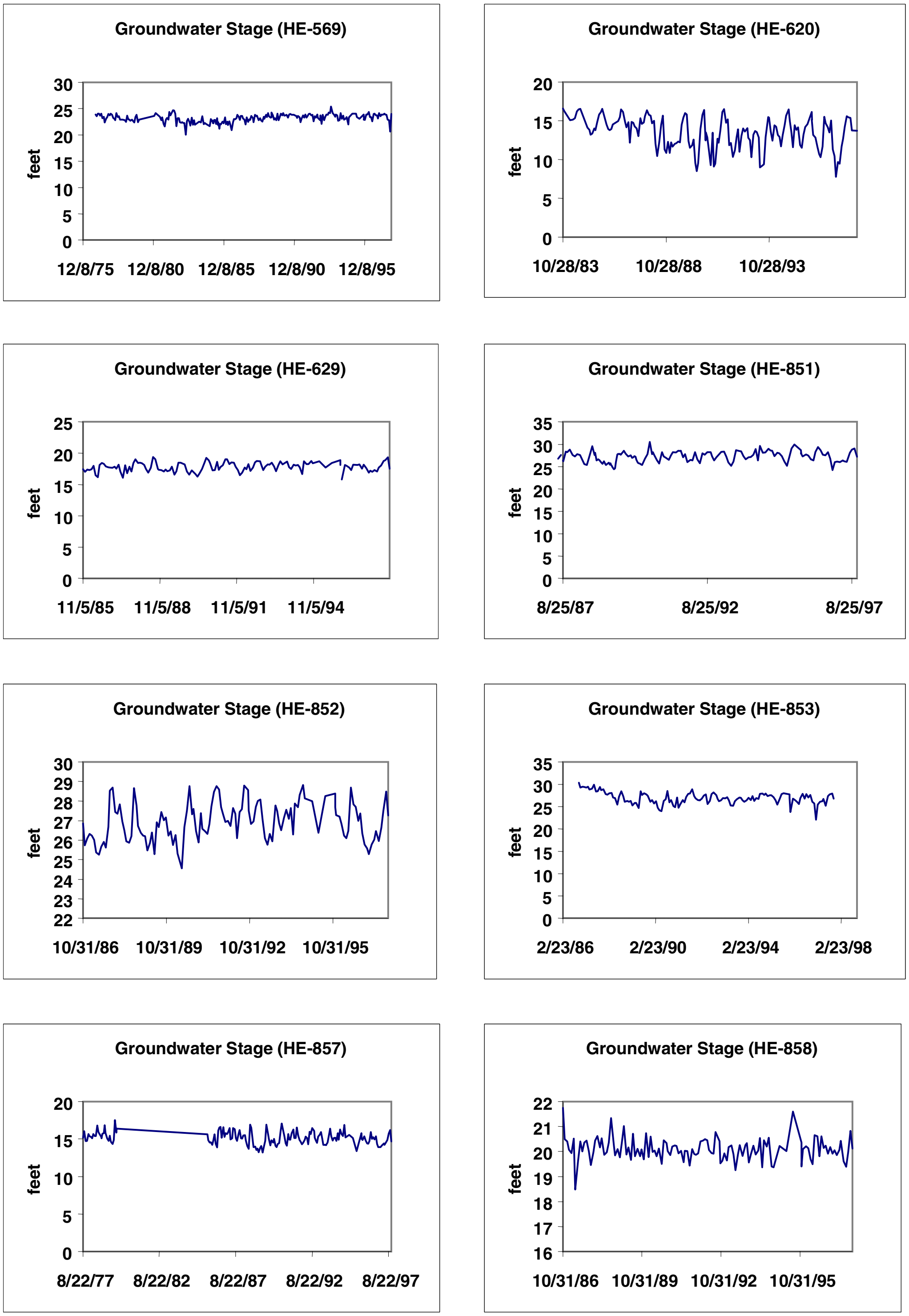

Figure B-10b. Ground Water Stage for Period of Record for SFWMD Ambient Monitor Wells.

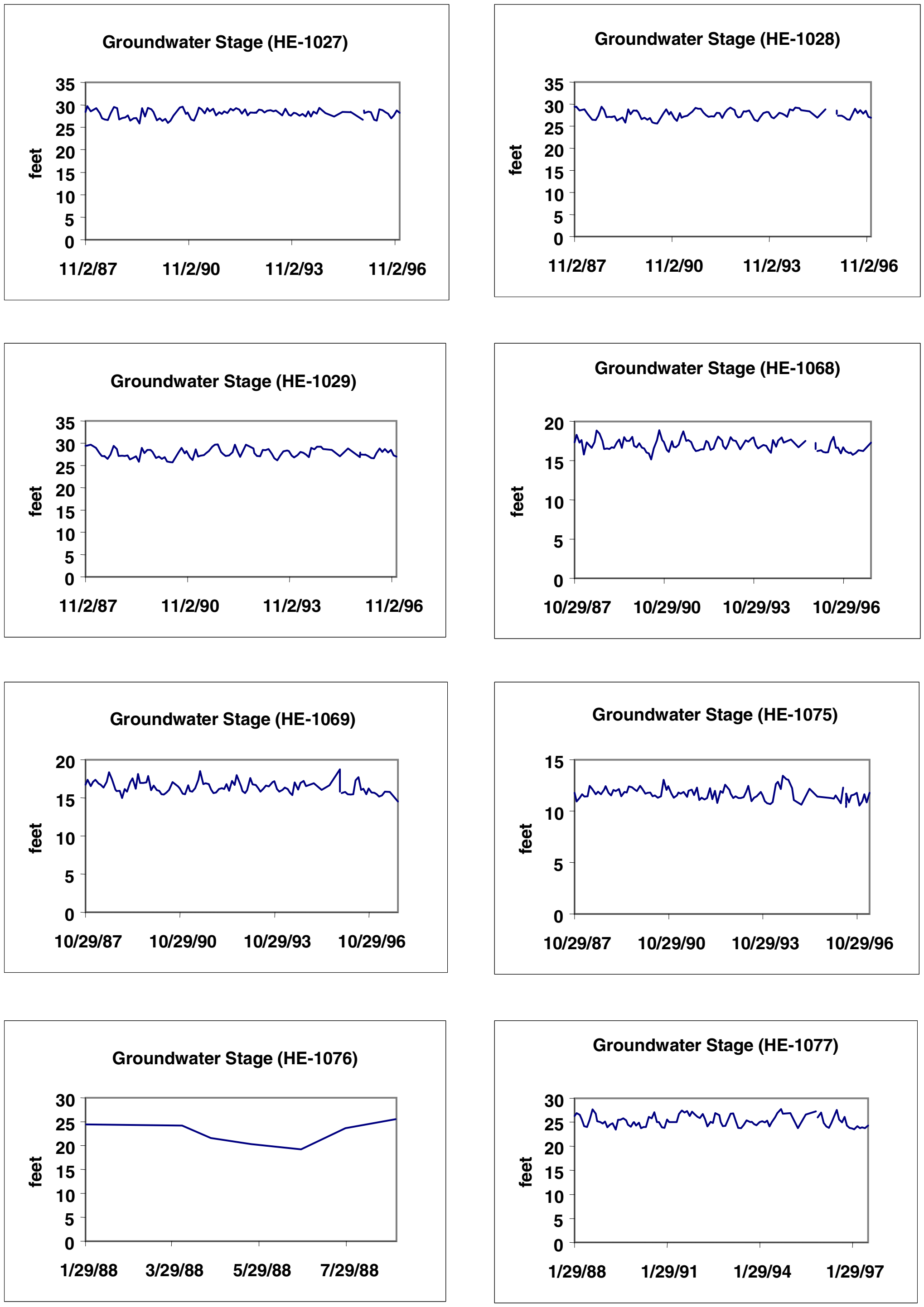

Figure B-10c. Ground Water Stage for Period of Record for SFWMD Ambient Monitor Wells.

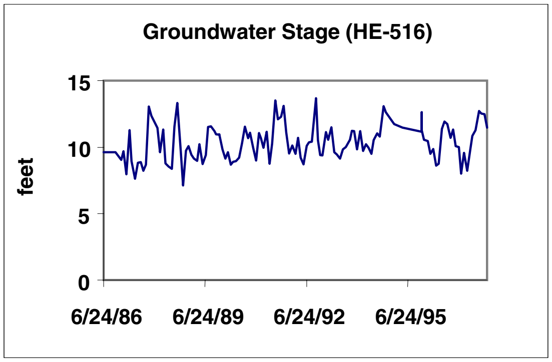

Figure B-10d. Ground Water Stage for Period of Record for SFWMD Ambient Monitor Wells.

Table B-7. Active Ground Water Wells in the Caloosahatchee Basin.

	Well	Basin	Depth (feet)	Casing Depth (feet)	Start Year
1	HE-517	West Caloosahatchee	158	135	1977
2	HE-529	West Caloosahatchee	155	135	1976
3	HE-556	West Caloosahatchee	155	135	1976
4	HE-558	West Caloosahatchee	13	3	1977
5	L-1137	West Caloosahatchee	20	15	1973
6	L-727	West Caloosahatchee	71	67	1973
7	L-729	Orange River	103	81	1977
8	L-1418	Orange River	62	55	1973
9	L-2186	Orange River	160	133	1977
10	HE-1075	East Caloosahatchee	155	135	1987
11	HE-529	West Caloosahatchee	155	135	1987
12	HE-554	West Caloosahatchee	15	5	1983
13	HE-1027	East Caloosahatchee	7	4	1987
14	HE-1028	East Caloosahatchee	60	20	1987
15	HE-1029	East Caloosahatchee	182	92	1987
16	HE-852	East Caloosahatchee	14	9	1986
17	HE-853	East Caloosahatchee	61	17	1986
18	HE-5	East Caloosahatchee	13	8.7	1983
19	HE-1076	East Caloosahatchee	340	300	1988
20	HE-1077	East Caloosahatchee	10	5	1988
21	HE-555	West Caloosahatchee	270	250	1975
22	HE-851	West Caloosahatchee	13	5	1987
23	HE-559	West Caloosahatchee	165	155	1975
24	HE-560	West Caloosahatchee	80	70	1977
25	HE-569	West Caloosahatchee	17	11	1975
26	HE-1068	Flagpole	160	60	1987
27	HE-1069	Flagpole	13	3	1987
28	HE-629	Flagpole	144	133	1985
29	HE-858	East Caloosahatchee	17	12	1986
30	HE-557	West Caloosahatchee	100	80	1976
31	HE-558	West Caloosahatchee	13	3	1996
32	HE-620	West Caloosahatchee	350	171	1983
33	HE-857	East Caloosahatchee	17	12	1977
34	HE-516	West Caloosahatchee	273	270	1986

Water Supply

Pumpage data for water supply were obtained from growers for some of the water use permits through the Regulation Department at SFWMD. The pumpage data were reported as total monthly values for the period from 1993 to present. These data are available for 130 permits in the basin. There are 97 permits that obtain water from the Caloosahatchee River. Of these permits, 35 have submitted pumpage reports to the SFWMD. The quality of the data ranges from estimated monthly values to total monthly water use to summation of actual daily water use. The quality of the individual records has not been assessed. Unfortunately, it was not possible to obtain a complete set of records for evaluation at this time.

Water Control District Hydrologic Data

An attempt was made to obtain hydrologic data from the fourteen Water Control Districts (WCDs) in the basin. Hydrologic data were available only for the East County Water Control District (ECWCD). Hydrologic data for other WCDs may be available through the SFWMD, but effective retrieval was not possible. The ECWCD hydrologic data consists of stage at selected control structures in the three major basins (**Table B-8**). The ECWCD also monitors stage in several canals. Canal stage data collection began in 1995 while canal stage at weirs began in 1985. These data will be used to evaluate the efficacy of weir head manipulation on local water storage and control of downstream flooding.

Table B-8. Monitored Weirs in the East County Water Control District.

	Orange River	Hickey Creek	Bedman Creek
1	S-A-1	S-HC-I	S-D-1
2	S-A-2	S-M-I	S-H-1
3	S-NM-1	S-HC-2	S-H-3
4	S-OR-I-SE	S-A-2	S-LB-1
5	S-OR-I	S51-I-2	S57-24-2
6	S-R-I	S-H-3	S-LJ-1
7	S-SF-I		S-LD-1
8	S-SF-2		S57-1-2
9	S-YT-I		S57-12-1
10	S-ML-1B		S57-13-1
11	S-ML-1A		S57-24-2
12	S-ML-2		
13	S-ML-4		

DISCUSSION

The data collected during this task primarily came from the SFWMD. A few of the datasets came from NOAA and private companies. Most of the data from SFWMD were obtained through the standard SFWMD databases. As such, these data have been scrutinized for errors and aberrations. The flow data for the major structures on C-43 have been evaluated by USGS. A series of discharge measurements were made at each of the structures (S-77, S-78, and S-79) using the acoustic doppler current profiler. The measurements were used to develop rating curves for each structure. An analysis of the rating curves has been developed by USGS; they compared the actual discharge to the values estimated by the rating curve. The results indicate that the relative error in discharge is less than 10 percent, from 50 to 90 percent of the time at S-77 and S-79. The relative error at S-79 is greatest at discharge less than 1,000 cfs. Overall the rating at S-79 is considered excellent. At S-77, the relative error is less than 10 percent, 80 percent of the time. The relative error is greater than 10 percent, 70 percent of the time when flows are below 750 cfs. The rating at S-77 is very good at large flow and poor at low flows. The rating analysis for S-78 has not been completed.

The data from the permit pumpage files have not been checked and those data are not included in this report. The data from ECWMD appear to be reasonable and are readily available. There were not other data currently available that required review a part of this task deliverable.

There have been few hydrologic assessments in the Caloosahatchee Basin. In particular, a study of tributary discharge was conducted as part of the analysis of the Caloosahatchee Basin in the Miller et al. (1982) study of water quality in the Caloosahatchee River. Unfortunately the tributary flow data from that project has been lost, and it would require additional labor beyond the scope of this project to place that data into the data base.

One intent of this task was to convert the available weather data into input data sets suitable for hydrologic simulation modeling. It was found that there were insufficient hydrometerological data available in the basin to support standard hydrologic models. Each of the more powerful hydrologic models require weather data for estimating ET. Unfortunately, there are no long-term weather records of sufficient detail for conducting hydrologic simulations. For long-term simulation, it will be necessary to adapt the ET estimates from the lower east coast data which are based on meterological data collected at West Palm Beach.

It was expected that a specific model would have been selected for hydrologic simulation. There has been no agreement as to the appropriateness of any specific model for simulating the hydrologic behavior of the basin. No attempt has been made to convert these data into a data set to support a specific model.

The hydrologic data have been summarized in this report and the provided on the Southwest Florida Research and Education Center Website. The data sets are available as

ASCII files and Excel spreadsheets. Although it was intended that these data be developed into a relational database, there has been no agreement among the many potential users concerning the structure or content of the database, nor has there been agreement on the appropriate software. The recommendation has been to develop a simple, generic database that provides the available data in the most convenient format.

REFERENCES

Miller, T.H., A.C. Federico, and J.F. Milleson. 1982. *A Survey of Water Quality Characteristics and Chlorophyll a Concentrations in the Caloosahatchee River System, Florida.* Technical Publication 82-4. South Florida Water Management District, West Palm Beach, FL.

Appendix C
TAPE GRASS LIFE HISTORY METRICS ASSOCIATED WITH ENVIRONMENTAL VARIABLES IN A CONTROLLED ESTUARY

S.A. Bortone and R.K. Turpin
Florida Center for Environmental Studies

ABSTRACT

Twenty samples of tape grass were removed from four locations along a salinity gradient in the Caloosahatchee River in Lee County, Florida for each month in 1998. Examination of the environmental independent variables indicates a strong seasonal cycle for temperature and trend toward increasing chlorophyll levels during the year. Dependent response variables recorded for tape grass also indicated a seasonal pattern that mimicked the temperature cycle. There was a time lag in maximal life history attributes. Number of shoots per sample, number of blades per sample, and number of blades per shoot had highest values during the warmer months (i.e., May – August). Blade length, blade width, and biomass were higher during the later part of the summer and early fall. Reproductive attributes of the plants (i.e., number of male and female flowers) were highest during the fall. The salinity gradient, that was part of the study design, was weak and accounted for only a small part of the variation observed between locations along the river. Typically the end of the year parameter levels were higher than the beginning of the parameter levels for all response variables among plants. It is suspected that this is due to the inordinately heavy rains during early 1998 that led to lower salinities at all locations. These normally freshwater plants were apparently less stressed because of the lower salinity conditions in the estuary. This situation may have provided a "boost" to their growth that helped expand the extent, size, and fitness of tape grass within the estuarine system. A paradox was revealed in that higher plant growth parameters were recorded among plants from the higher salinity portions of the river. During 1998, salinities were low at the most seaward location but water clarity was greater, thus providing conditions that may have facilitated growth of this normally freshwater plant in an estuarine ecosystem.

INTRODUCTION

Monitoring seagrasses (including all forms of submerged aquatic vegetation - SAV) is rapidly becoming one of the foremost methods to determine the overall health and condition of the aquatic environment (Dennison et al., 1993; Stevenson et al., 1993). Seagrasses have shown particular promise in detecting specific factors that may influence both short and long-term changes to nearshore aquatic ecosystems. More recently, this has been especially true for evaluating the relative health and condition of estuaries (e.g., Johannson, 1991).

Tape grass, *Vallisneria americana* Michx. (also known as water celery, eel grass, American eel grass, and American wild celery) is widely distributed in nearshore aquatic habitats (see Bortone et al. 1998 for an annotated bibliography on the life history of this species). Tape grass is generally a freshwater species, but it is also an important component of the oligohaline estuarine SAV community (Twilley and Barko, 1990; Adair, 1994; Kraemer et al., 1999). Because it inhabits the upper portions of estuaries, it is often subjected to wide fluctuations in salinity due to intense freshwater runoff events after having been subjected to higher salinity exposures due to periods of little runoff or rainfall (Zieman and Zieman, 1989).

The Caloosahatchee River in Southwest Florida serves as a conduit for fresh water from Lake Okeechobee to the Gulf of Mexico, especially during times of excessively heavy rain events. Tape grass occurs in well defined beds in shallow waters below a water control structure (Franklin Lock and Dam). Discharge profiles indicate that freshwater releases normally occur during the summer months (June, July, and August) when thunderstorms drop excessive rain onto the surrounding area (Chamberlain and Doering 1998). Also, in anticipation of extra-heavy rain events (such as those resulting from a hurricane) water management authorities release water from Lake Okeechobee during the late spring and summer to allow for situations when excessive storm water may have to be retained in Lake Okeechobee to prevent flooding. Because of this scenario, managing authorities need to know how the retention and release of fresh water affect the contiguous estuarine ecosystem. Monitoring tape grass life history features is one way to examine the impact of these freshwater releases.

Presented here are the results of an initial baseline monitoring assessment study to establish the life history parameters of tape grass, relative to salinity variations in the Caloosahatchee River. While the study is in its infancy, the basic methodology and general results serve to guide the development and implementation of future studies that seek to use seagrasses to assess estuarine conditions. The study was designed to obtain information on both life history attributes of tape grass inhabiting the upper estuarine portions of the Caloosahatchee River and to draw inferences on the association of these response dependent variables have with the environmental independent variables. The utility in knowing the species life history parameters and their relationship with the environmental variables will facilitate future management decisions regarding options to release or retain freshwater discharges to the Caloosahatchee River. Ultimately, these data will serve as a basis to maintain ecological integrity of this ecosystem and may serve as a model for regulation and control of other estuarine areas.

MATERIALS AND METHODS

Description of the Study Area

The area of study is located within the Caloosahatchee River (**Figure C-1**) on the southwestern coast of Florida. The study area was chosen because tape grass beds occur in the river along a distance exposed to a broad range of salinity that varies during the year. As tidal flux is usually less than a meter and winds are not consistently strong in any direction, salinity is strongly influenced by the amount of rainfall in the immediate area and the overall drainage basin that extends as far east as Lake Okeechobee.

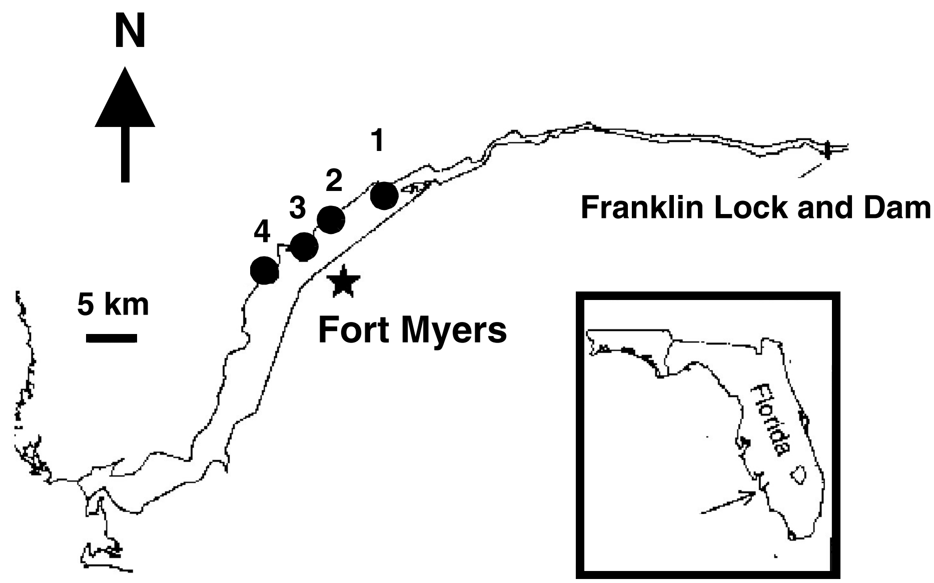

Figure C-1. Map of the Study Area, Indicating Sampling Stations within the Caloosahatchee River.

Study Design

At each of four locations (**Figure C-1**) one pair of 100 meter (m) transects (one perpendicular to shore and one parallel) was established at two sites (A, downstream; B, upstream). The intersection of the transects for each site was selected in situ by visually detecting the presence of tape grass. The beginning end of each perpendicular transect was placed at the shoreline, thus each transect intersection (i.e., “midpoint”) was located 50 m from shore. Each parallel transect had the midpoint of the perpendicular transect as its midpoint.

Each transect was divided into five intervals (1-20 m, 21-40 m, 41-60 m, 61-80 m, 81-100 m); monthly, a different specific distance within each interval was selected using a random number generator without replacement. Thus, at each of four locations during each month beginning in January 1998, a total of 20 discrete samples for tape grass were collected from two sites, at two transects, and at five intervals.

Sampling Methods

Monthly during 1998, tape grasses were sampled at a randomly selected location along each transect by placing a 0.1-m^2 weighted PVC quadrat frame on the river bottom and subsequently removing all tape grass plants within the quadrat. Samples were placed in plastic bags, labeled, and stored on ice in an insolated dark box, returned to the laboratory, and, within 24 hours, measured for the dependent variables. Only tape grasses were collected. If the sample contained epiphytes or attached vegetation such as *Ruppia maritima,* notes were taken as to their presence and relative abundance.

Below are each of the independent and dependent variables measured during this study with a brief definition and description of the method used to assess each variable.

INDEPENDENT VARIABLES

The independent environmental variables were recorded monthly at each sample location. Most variables were recorded in situ. Additionally, water samples were collected 0.5 m below the surface to assess total suspended solids (TSS), chlorophyll a, and color. The water samples were placed on ice for up to five hours and brought to the Lee County Environmental Laboratory for detailed water quality analysis.

- Date - Recorded by Year Month Day (e.g., 19990131 = 31 January 1999) as a single number to facilitate logical sorting of the database.
- Location - Four sample locations on the north side of the Caloosahatchee River (numbered 1, 2, 3, and 4): Location 1, 3.5 km west of the I-75 bridge (26° 41’23” N, 81° 49’48” W); Location 2, 2 kilometers (km) east of the (Business) US 41 bridge (26° 40’21” N, 81° 51’52” W); Location 3, between the (Business) US 41 and US 41 bridges (26° 39’18” N, 81° 52’48” W); Location 4, 3 km west of the US 41 bridge (26°38’37” N, 81°54’8” W).
- Site - Two sample sites (A, downstream; B, upstream) per location, separated from each other by 100 to 200 m.
- Direction - Direction or orientation of sample transect (either perpendicular or parallel to shore at each site).

- Distance - Distance along the 100-m transects. Each transect was divided into five, 20-m intervals. Samples were collected within each 20-m interval at distances selected from a random number generator without replacement. Distances increased going offshore (perpendicular transects) or upstream (parallel transects).
- Time - Local time of day (EST or EDT) at the beginning of sampling at each location recorded as military time.
- Depth - Water depth to the nearest centimeter at the center of each 20-m sample interval along each transect. Water depths were measured on only one occasion throughout the entire study area (all within 1 hour) to reflect the relative depth among samples.
- Tidal stage - Category of tidal stage (L=low, H=high, E=ebbing, F=flooding) at time of sampling determined from the relative position of "Fort Myers" using a tidal projection software program (Nautical Software Inc., Beaverton, Oregon).
- Temperature - Surface water temperature (measured to the nearest degree Celsius).
- Salinity - Salinity estimated to the nearest ppt (part per thousand) using a temperature corrected refractometer.
- Secchi depth - Vertical Secchi disk (20-cm [centimeter] diameter) depth measured to nearest centimeter as an indicator of water clarity.
- TSS - measured as milligrams per liter (mg/L, detection limit = 1 mg/L).
- Chlorophyll a - Measured as milligrams per cubic meter (mg/m^3, detection limit = 0.5 mg/m^3).
- Color – Measured in "color units" (cu, detection limit = 1 cu) at 465 nanometers (nm), Platinum Cobalt standard of 500 APHA, measured at 500 cu undiluted stock; 300 cu, 30 milliliters (ml) diluted to 50 ml; 100 cu, 10 ml stock diluted to 50 ml; 50 cu, 5 ml diluted to 50 ml with de-ionized H_20.

DEPENDENT VARIABLES

All dependent variables were measured in the laboratory on samples placed on ice for 24 hours, except where noted.

- Number of Shoots - Number of *V. americana* shoots counted from each sample. Individual shoots (i.e., "plants") may have occurred singly or attached via underground rhizomes (when attached to other plants, each shoot was counted separately).

- Number of Blades - Number of *V. americana* blades (“leaves”) counted from each sample. Where the number of shoots was >30, the number of blades was counted from a subsample of 30 shoots; the number of blades was counted in the subsample and the total number of blades was calculated for the sample.
- Number of Male and Female Flowers - Counted from the entire sample collected at each location.
- Blade Length - Mean blade length measured in millimeters (mm) and calculated to nearest 0.1 mm from the five longest blades.
- Blade Width - Mean blade width was measured in mm and calculated to nearest 0.1 mm from the five widest blades.
- Weight - Dry weight in grams (to nearest 0.001 gram [g]) of the entire sample. Each sample was dried for 5 days in an oven at 80 °C. Where number of shoots in a sample exceeded 30, a subsample of 30 shoots was dried and weighed; dry weight for the entire sample was then calculated.

Analyses

Data were analyzed using the SAS® statistical package (SAS, 1995). Pearson and Spearman rank correlation coefficients were used to determine the associations between all variables. Stepwise Regression was used to assess the significance and degree each variable contributed to explain the variation observed for the dependent variables. Graphs were prepared using SigmaPlot® software.

RESULTS

Independent Variables

Temperature – Temperature generally followed a pattern of increase and decrease typical for the seasonal variation in Southwest Florida (**Figure C-2**). Lowest temperatures were in December and January (17-18 °C) and warmest during June (32-34 °C). Monthly temperature profiles at all four locations followed a seasonal pattern with the exception during November, when all locations were abruptly higher. This was due to local warm weather conditions.

Salinity – Variation in salinity can most often be attributed to tidal effects as well as local runoff and rains. As salinity was not measured on a consistent lunar cycle, it is not surprising that salinity showed only little evidence of a seasonal pattern. However, the annual profile does indicate evidence of the inordinately heavy rains that occurred during January – March, with residual runoff occurring until May 1998. Salinities were from 0 to

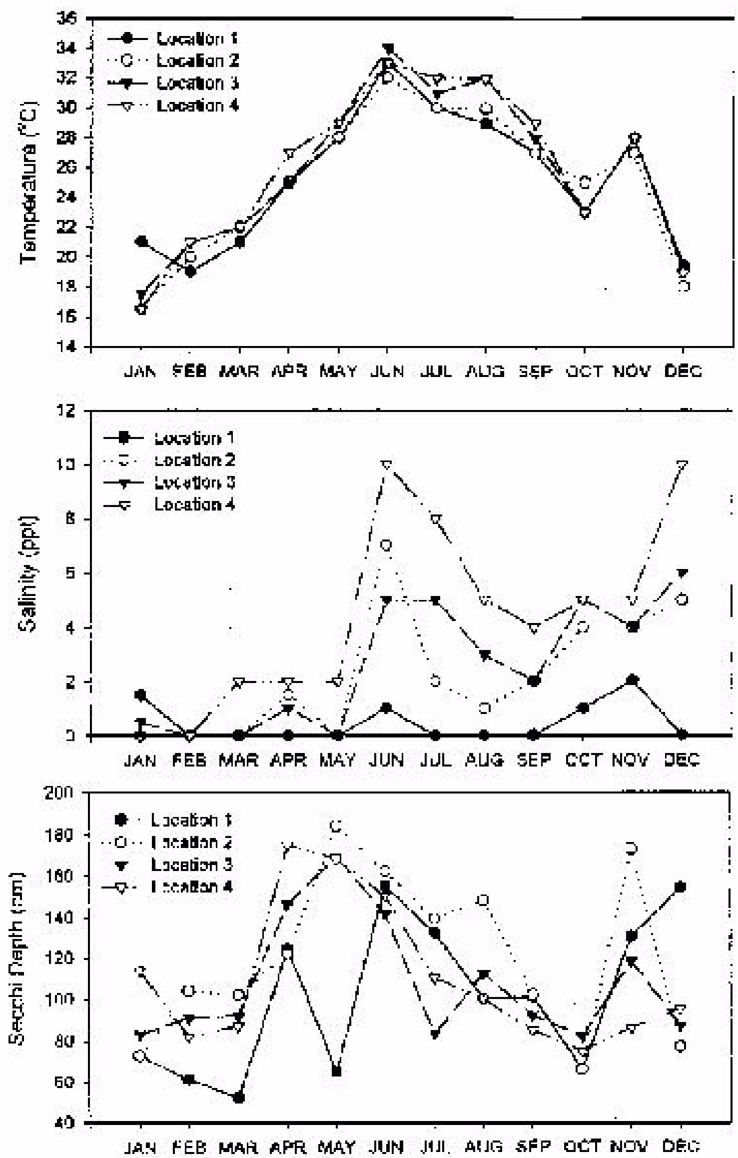

Figure C-2. Monthly Temparature (upper graph), Salinity (middle graph), and Secchi Depth (lower graph) Recorded at Each of the Sampling Stations.

10 ppt and most were at or below 5 ppt. Locations were chosen so that salinities would be likely to be lower upstream (Location 1), higher salinities would be furthest downstream (Location 4), with Locations 2 and 3 being intermediate. **Figure C-2** indicates that this was generally true as the lowest salinities were recorded at Location 1 (mean = 0.5 ppt/ month) and highest from Location 4 (4.4 ppt). However, considerable variability was noted at the intermediate distance locations and they were nearly identical with regard to salinity (2.2 ppt and 2.6 ppt for Locations 2 and 3, respectively). Lack of an obvious upstream-downstream salinity gradient was probably due to local mixing and runoff.

Secchi depth – Water clarity, as measured by Secchi depth, was highly variable (**Figure C-2**) with little evidence of a seasonal pattern except that water clarity was greater during the spring and early summer and poorest during the winter and early fall. The high variability and difference between the other sites in water clarity at Location 1 was probably due to the influence of variable winds and boat traffic proximate to this location.

TSS – Inspection of **Figure C-3** indicates that measures of this variable did not display a pattern but that differences between locations were relatively small. Notable, however, were the two peaks in TSS at Location 4 in July and September.

Chlorophyll a – This variable was generally low early during the sampling period but gradually increased toward the late summer and fall (**Figure C-3**). Generally, Locations 2 and 4 had higher levels during the period of increased chlorophyll levels.

Color – Color information can prove an important indicator of the influence of freshwater runoff because, as runoff increases (particularly from natural, tannic stained areas such as woodlands), water becomes darker in color. **Figure C-3** indicates that the color pattern was similar to the rainfall pattern in the area during 1998.

Dependent Variables

Number of samples with shoots (**Figure C-4**) indicated an overall annual trend to increase during the sampling period among all locations except Location 1, the most upstream sample. Locations 2 and 3 displayed the most dramatic increase in the number of samples with shoots. While the number of samples with shoots at Location 4 increased during 1998, it was always highest among all locations. The number of samples with shoots displayed no seasonal trends at Location 1.

Monthly patterns were similar among the dependent variables: shoots per sample, blades per sample, and blades per shoot (**Figure C-5**). These variable parameters were higher during the warmer months of the year (May – August) and lower during months when the water temperature was cooler (January – March and September – December). The number of shoots and blades per sample were higher at Location 4.

Blade lengths and blade widths increased toward the late summer and early fall at all locations (**Figure C-6**). In contrast, the blade width/blade length ratio was lowest

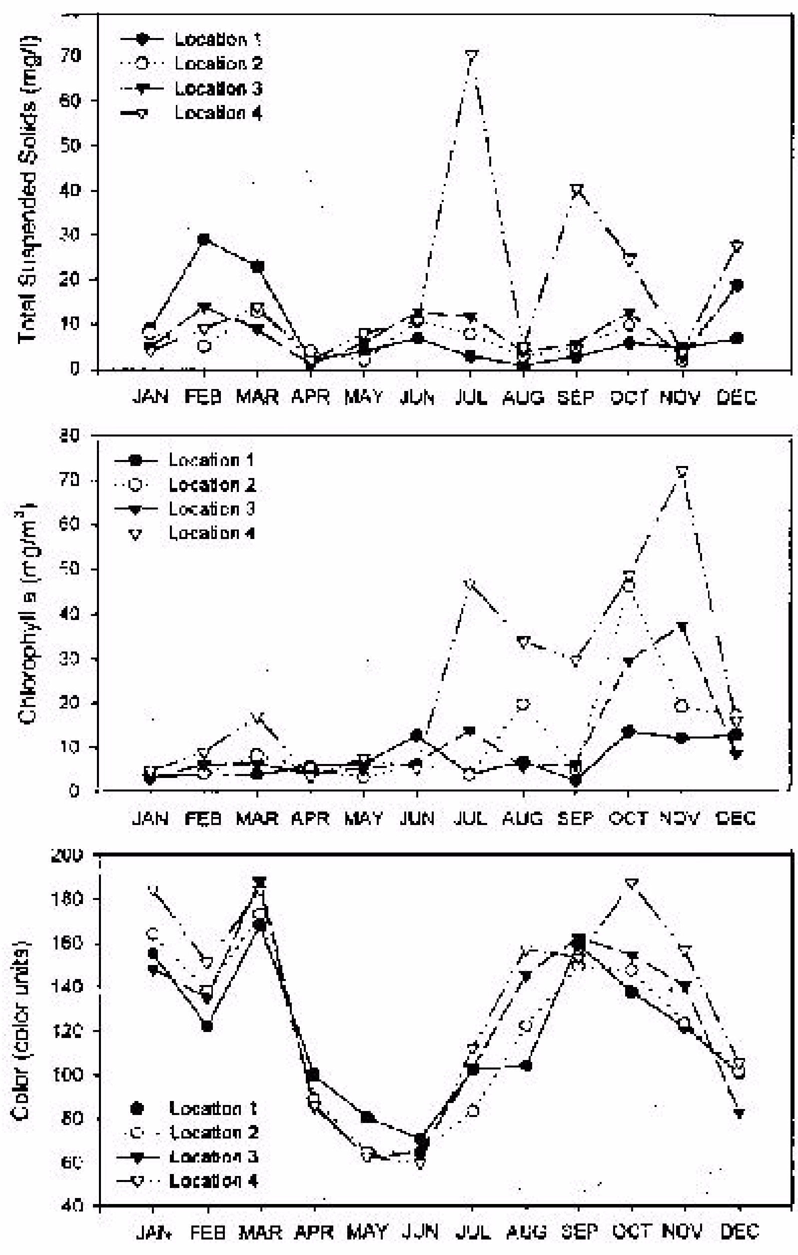

Figure C-3. Monthly Total Suspended Soilds (upper graph), Chlorophyll A (middle graph), and Color (lower graph) Recorded at Each of the Sampling Locations.

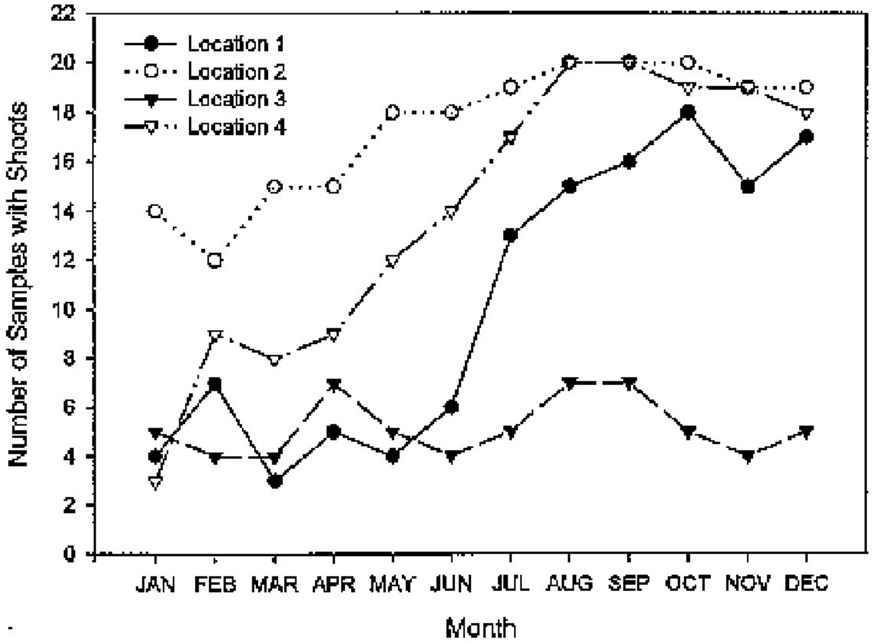

Figure C-4. Monthly Trend among Locations for the Number of Stations with Shoots.

during this period. While a distinct trend seems lacking among these variables, blade length was typically longer at Location 4.

Just as the blade lengths and widths increased during the late summer and early fall, so did the number of female and male flowers (**Figure C-7**). It appears, however, that the peak flower months (highest at Location 4) were maximal during August – October. The maximum values for blade lengths and widths were high for an expanded season but were highest during July - September.

Biomass (as measured by dry weight per sample and per shoot) was low during the early part of the year (January – May) but increased during June and July and remained relatively high until the late fall (**Figure C-8**).

Variable Associations

To determine the potential relationships among and between both independent and dependent variables, a Pearson Product correlation coefficient (r) was calculated between all possible pairs of variables. Significant ($p < 0.05$) and strong ($r > \pm0.50$) correlations among independent variables were noted: date with salinity (+0.52) and chlorophyll (+0.51); location with salinity (+0.51); and Secchi depth with color (-0.64). Among the dependent variables significant ($p < 0.05$) and strong ($r > \pm0.75$) relationships were

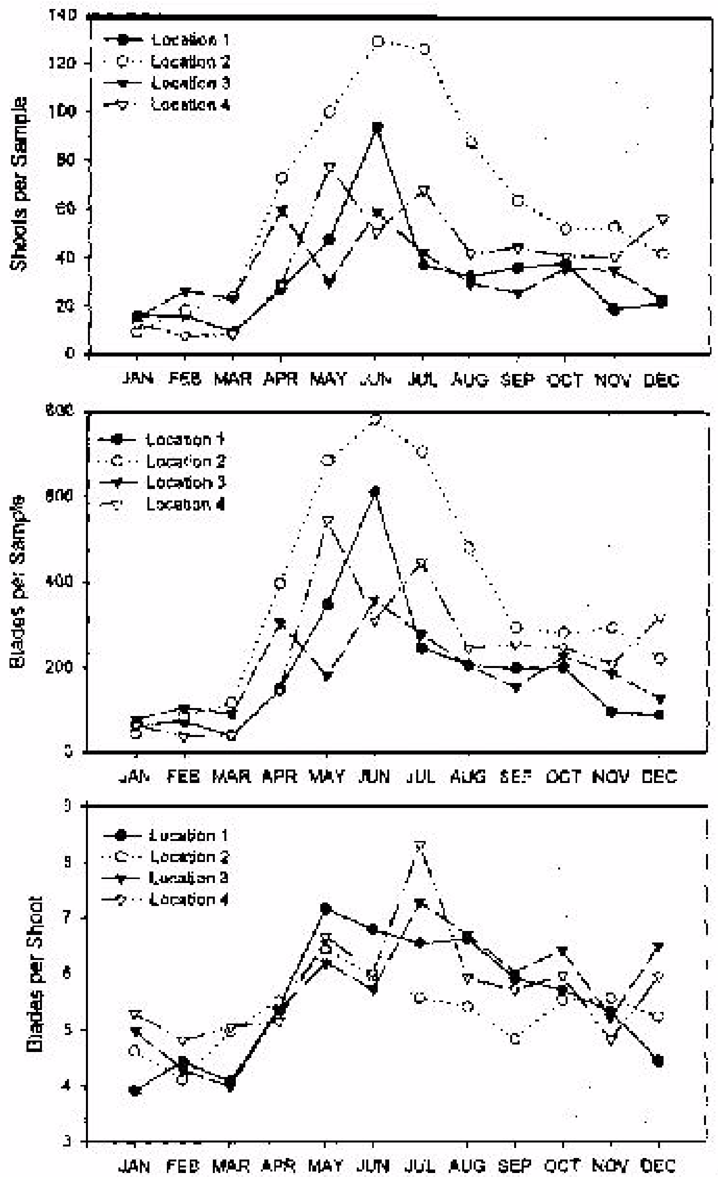

Figure C-5. Monthly Trend among Locations for the Number of Shoots per Sample (upper graph), Number of Blades per Sample (middle graph), and Number of Blades per Shoot (lower graph).

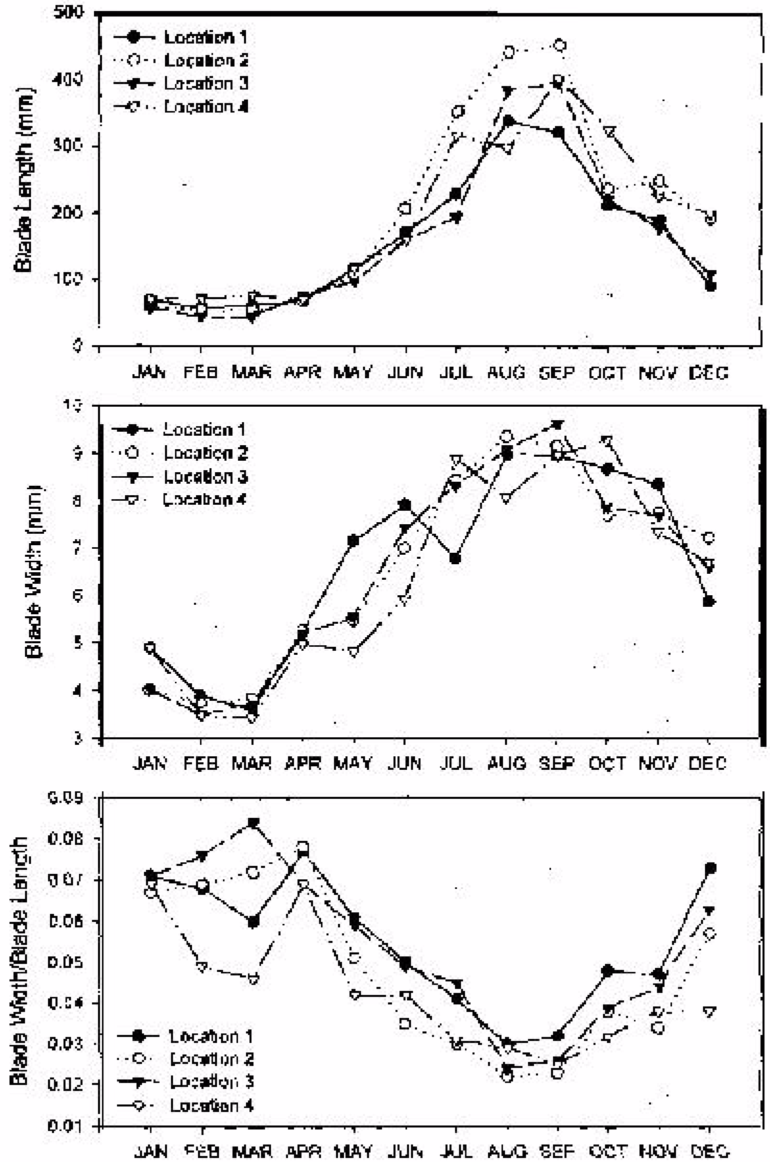

Figure C-6. Monthly Trend among Stations for Mean Blade Length (upper graph), Mean Blade Width (middle graph), and Width/Blade Length Ratio (lower graph).

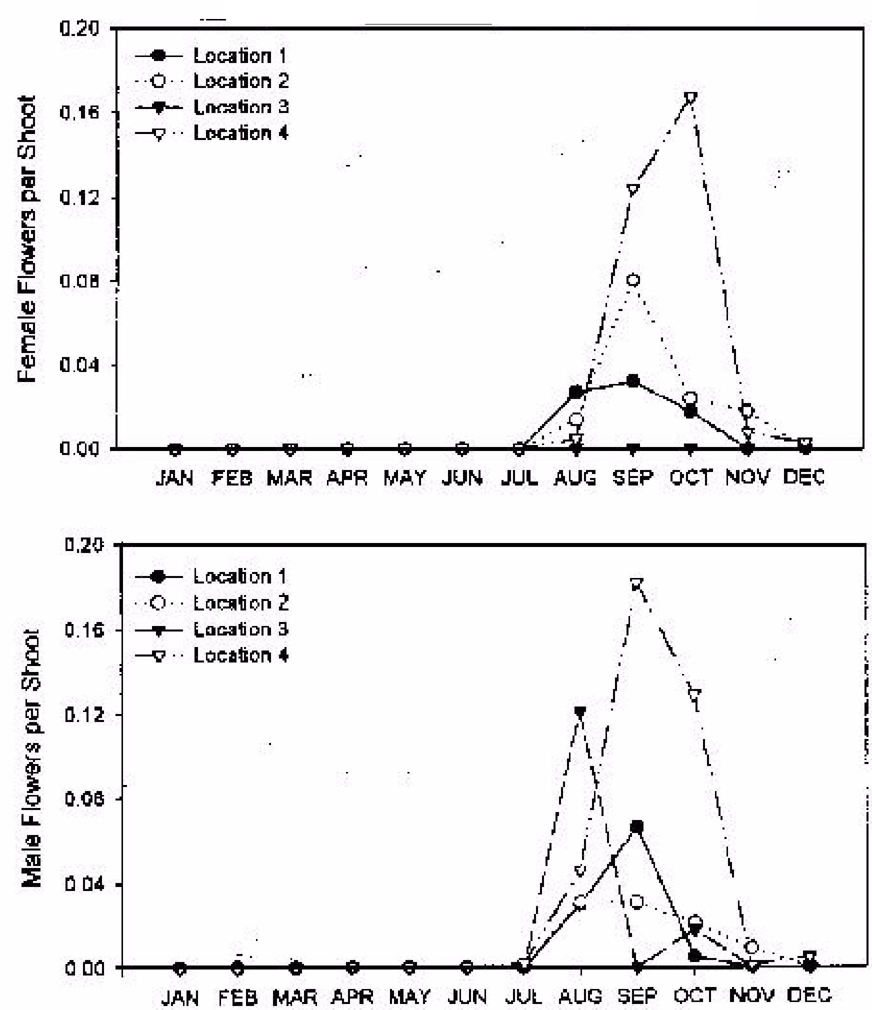

Figure C-7. Monthly Trend among Locations for the Number of Female Flowers per Shoot (upper graph), and Number of Male Flowers per Shoot (lower graph).

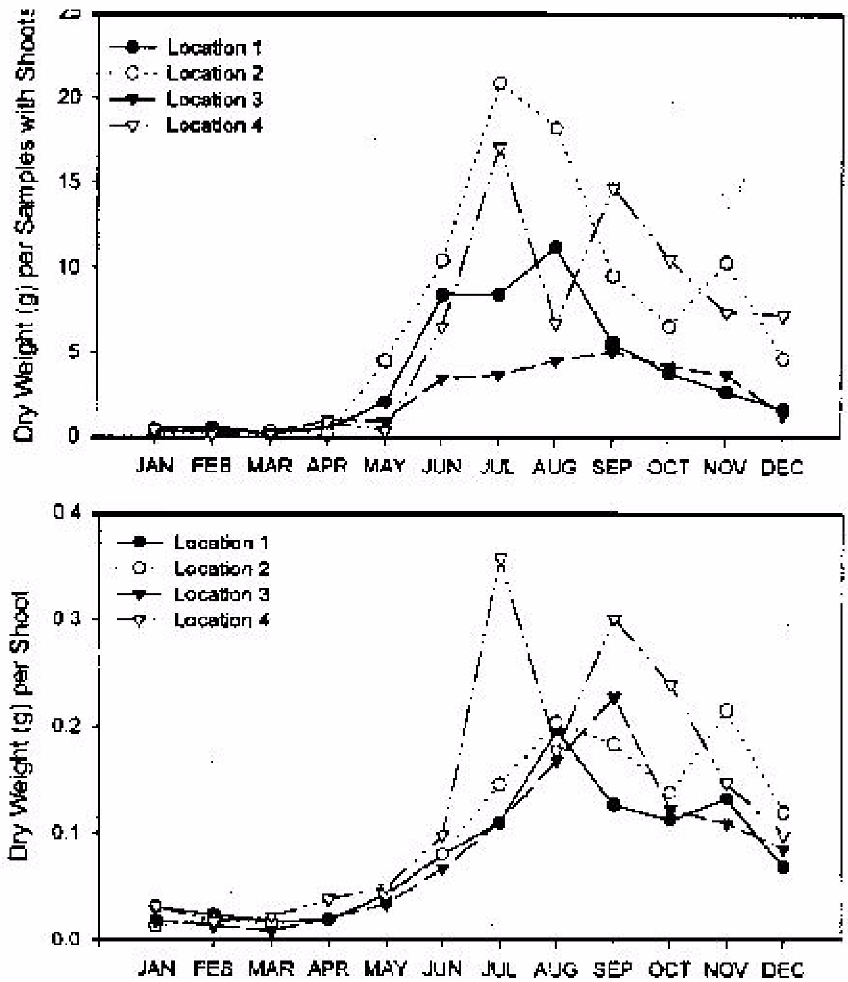

Figure C-8. Monthly Trend among Locations for the Dry Weight per Samples with Shoots (upper graph) and the Dry Weight per Shoot (lower graph).

observed: number of shoots with number of blades (+0.96); blade length with blade width (+0.88) and weight (+0.77).

A comparison of Spearman rank correlation coefficients (a nonparametric measure of association) indicated that significant and strong associations occurred between salinity and chlorophyll (+0.55), as well as between Secchi depth and color (-0.57). Among the dependent variables there were several significant and strong Spearman rank correlations: number of shoots with blade length (+0.88), blade width (+0.88), and weight (+0.95); number of blades with blade length (+0.89), blade width (+0.89), and weight (+0.96); blade length with blade width (+0.97) and weight (+0.96); blade width with weight (+0.95).

Interestingly, there were no significant correlations of any independent with any dependent variable.

Stepwise Regression

A stepwise regression procedure was used to elucidate the amount of variation in the dependent variables that could be explained by the data gathered during this study. The results are summarized in **Table C-1**.

Inspection of these analysis results indicates that only one or two of the alternative dependent variables can explain most of the variation within each of the dependent variables. For example, variability in the number of shoots can be almost completely predicted from the number of blades. Number of blades and number of shoots are clearly codependent as are blade length and blade width. Nearly 60 percent of the variation in shoot weight can be explained by blade length. Less reliable is the prediction of the number of male and female flowers as only 14.3 and 18.7 percent, respectively, of the variation of these parameters can be explained with the model offered here.

The main purpose of this analysis, however, was to gain insight into the environmental variables that may be associated with variation in the dependent variables. The number of shoots was only significantly associated with variation in TSS; blade width with temperature; blade length with five factors (location, depth, temperature, Secchi depth, and color); blade width with location, depth, temperature, salinity, Secchi depth, chlorophyll and color; number of male flowers with depth and color; number of female flowers with location, Secchi depth, and color; and weight with six factors (location, depth, temperature, Secchi depth, TSS, and color).

Of all the factors, location, depth, temperature, Secchi depth, and color are apparently the most influential in affecting (or being associated with) the dependent variables.

Table C-1. Summary of the Stepwise Procedures To Build a Predictive Model for Each of the Dependent Variables.

Variable	Number of Shoots	Number of Blades	Blade Length	Blade Width	Number Male	Number Female	Weight
Date							
Location			0.001	0.005		0.002	0.001
Distance							
Depth			0.002	0.004		0.003	0.003
Temperature		0.001	0.004	0.002			0.001
Salinity				0.001			
Secchi			0.001	0.001		0.002	0.001
TSS	0.001						0.007
Chlorophyll A				0.006			0.002
Color			0.007	0.004	0.016	0.007	
Number of Shoots		0.921		0.021	0.007	0.017	0.002
Number of Blades	0.921		0.013				0.110
Blade Length		0.001		0.779	0.003	0.135	0.600
Blade Width	0.007	0.001	0.779				0.017
Number Male							0.011
Number Female	0..001		0.003				0.004
Weight	0.001	0.002	0.062	0.013	0.113	0.018	
Total R^2	0.929	0.925	0.874	0.835	0.143	0.187	0.754

DISCUSSION

Donnermeyer and Smart (1985) noted that seasonal growth in tape grass was maximal during mid to late July in the fresh waters of the Mississippi River. The dependent response variables recorded here for tape grass followed a similar seasonal pattern. There were, however, slight seasonal differences as to when the response variables were maximal. The number of shoots increased in the spring and stayed high in the summer while declining in the fall. This was also true for the number of blades and blade/shoot ratio. The attributes of the plants associated with size (i.e., blade length, blade width, and weight) all displayed greater values in midsummer and late fall. The reproductive season for tape grass, indicated by the number of male and female flowers, was highest during fall. Tape grasses have seasonally lagged life history features which may each be useful in assessing temporal aspects of stress in estuaries.

The absolute number of plants in the area, as indicated by the number of samples with shoots (**Figure C-2**), shows a slightly different seasonal pattern. The number of samples with shoots increased at three of the four locations (Location 1 being the exception). This increase is important because the populations of shoots at these locations were dramatically higher in December than they were during the previous January. In fact, closer inspection of all the study results indicates that monthly parameter levels for virtually all variables recorded here were higher during the end of the year than the beginning of the previous year.

This feature of the tape grass populations for 1998 in the Caloosahatchee River may be attributable to several factors. The levels of all variables are apparently cyclic (probably temperature related) and therefore should have declined to lower levels in December, similar to those of the previous January, if the study had been continued. Preliminary evidence indicates that while parameter levels for all variables continued to decline, they were, nevertheless, higher than during the previous January (Bortone and Turpin, personal communication). A potentially testable hypothesis can be offered to explain the apparent annual increase in plant attributes during 1998. As indicated previously, the amount of annual rainfall during 1998 (especially during the early part of the year) was excessive. Since tape grass is primarily a freshwater plant, it has some growth inhibition when subjected to even moderate levels of salinity (Doering et al. 1999). As the plants were exposed to much lower salinities in 1998, it is reasonable to assume that the plants responded by becoming more numerous and larger during 1998 so that the 1999 population parameters for beginning the ‘new’ year would be higher than for the previous year.

Accepting this hypothesis leads to a paradox to explain the dependent variable responses. Generally, the highest plant parameters were recorded at Locations 2 and 4. Location 4 is furthest downstream, and plants at this location were thus subjected to the highest salinity. Interestingly, however, water clarity (as measured by Secchi depth) was highest at Locations 2 and 4 (122 cm and 110 cm, respectively) while water clarity was lowest at Locations 1 and 3 (102 cm and 108 cm, respectively). Thus, while salinities were higher, plant growth may have been accelerated because of increased light availability.

While an annual mean difference of only a few cm between Locations 3 and 4 may not seem important, it should be noted that the Secchi depths had to be measured some 200 – 400 m toward the center of the river as water depth at both locations was insufficient when water was clearest to obtain a Secchi depth measure at the specific site where plants were located. Our impression at the time (as indicated in our field notes) was that water clarity was greater at Location 4. Site specific measures of water clarity would probably have revealed a greater difference in water clarity between the two locations.

Doering et al. (1999) noted in the laboratory the tape grass plants from the Caloosahatchee River curtailed growth at salinities higher than 15 ppt. Also, laboratory (Doering et al., 1999) and confirming field observations (Kraemer et al., 1999) indicated that tape grass growth was inversely associated with salinity. An important balance must therefore be present for tape grasses to thrive in an estuary; enough water clarity to permit light penetration (generally associated with higher salinity water), and enough fresh water to reduce the stress associated with the effects of salinity. Future research efforts should more closely monitor the balance between the stress potential caused by higher salinity levels and the increases in plant growth afforded by higher levels of photosynthetically useful light waves resulting from increased water clarity.

Among the independent variables there was a linkage between location, depth, Secchi depth, and color. These variables are all location specific and should be expected to link together. Among the environmental variables identified as having a significant association with the response variables only temperature is not location dependent. It should be noted that color should be negatively related to Secchi depth because higher color levels interfere with water clarity.

CONCLUSIONS

Establishing a baseline of life history information on tape grass serves to help tract changes in the aquatic conditions that lead to favorable SAV growth in the oligohaline portions of the Caloosahatchee River. Our investigation indicates that plant life history attributes vary seasonally and spatially. More important, however, is the realization that plant growth attributes may each respond on a different time scale to the presence of conditions favorable for plant growth. Even more important is the recognition of the need to measure environmental factors with a high degree of specificity with regard to proximity to the sample locations and with a high degree of accuracy, increased frequency, and greater precision. Our study has hinted at the significance of the interactive aspects of temperature, salinity, and water clarity. It behooves estuary managers to specifically determine the interactive effects these factors have on SAV growth in estuaries. Once this determination has been made, then managing estuaries to increase SAV growth (and subsequently provide abundant, natural habitat for the community of organisms associated with SAV) will become a reality.

ACKNOWLEDGMENTS

We thank D. Haunert, P. Doering, R. Chamberlain, and A. Steinman of the South Florida Water Management District (SFWMD) for providing guidance on the study design and for answering numerous questions regarding tape grass. We also thank T. Barnes for laboratory and sampling assistance. M. Giles and J. Evans reviewed an earlier draft of this manuscript. Lee County Environmental Laboratory staff (K. Kibby, Director) conducted the water quality analyses. Funding for this study was provided by the SFWMD and the Florida Center for Environmental Studies.

REFERENCES

Adair, S.E., J.L. Moore, and C.P. Onuf. 1994. Distribution and Status of Submerged Vegetation in Estuaries of the Upper Texas Coast. *Wetlands,* 14 (2):110-121.

Bortone, S.A., M.P. Smith, and R. K. Turpin. 1998. *Indexed Annotated Bibliography to the Biology and Life History of Tape Grass* (*Vallisneria americana*). Florida Center for Environmental Studies, Tech. Ser. 4:I-ii, 1-77. Florida Atlantic University (Northern Palm Beach Campus).

Chamberlain, R.H., and P.H. Doering. 1998. Freshwater Inflow to the Caloosahatchee Estuary and the Resource-Based Method for Evaluation. In: S.F. Treat (ed.). *Proceedings of the Charlotte Harbor Public Conference and Technical Symposium*. Technical Report No. 98-02. Charlotte Harbor National Estuary Program. North Fort Myers, FL. pp. 81-90.

Dennison, W.C., R.J. Orth, K.A. Moore, J.C. Stevenson, V. Carter, S. Kollar, P.W. Bergstrom, and R.A. Batiuk. 1993. Assessing Water Quality with Submerged Aquatic Vegetation. *Bioscience,* 43:86-94.

Doering, P.H., R.H. Chamberlain, K.M. Donahue, and A.D. Steinman. 1999. Effect of Salinity on the Growth of *Vallisneria americana* Michx. from the Caloosahatchee Estuary, Florida. *Florida Scientist,* 62 (2):89-105.

Donnermeyer, G.N. and M.M. Smart. 1985. Biomass and Nutritive Potential of *Vallisneria americana* Michx. in Navigation Pool 9 of the Upper Mississippi River. *Aquatic Botany,* 22 (1):33-44.

Johannson, J.O.R. 1991. Long-Term Trends of Nitrogen Loading, Water Quality and Biological Indicators in Hillsborough Bay, Florida. In: Treat, S.F. and P.A. Clark (eds.), *Proceedings, Tampa Bay Area Scientific Information Symposium 2*. Text, Tampa, FL. pp. 157-176.

Kraemer, G.P., R.H. Chamberlain, P.H. Doering, A.D. Steinman, and M.D. Hanisak. 1999. Physiological Responses of Transplants of the Freshwater Angiosperm *Vallisneria americana* along a Salinity Gradient in the Caloosahatchee Estuary (Southwestern Florida). *Estuaries*, 22 (1).

SAS. 1995. *SAS User's Guide*. SAS Institute, Inc. Raleigh, NC.

Stevenson, J.C., L.W. Staver, and K.S. Staver. 1993. Water Quality Associated with Survival of Submerged Aquatic Vegetation along an Estuarine Gradient. *Estuaries,* 16: 346-361.

Twilley, R.R., and J.W. Barko. 1990. The Growth of Submerged Macrophytes under Experimental Salinity and Light Conditions. *Estuaries,* 13(3):311-321.

Zieman, J.C. and R.T. Zieman. 1989. *The Ecology of Sea Grass Meadows of the West Coast of Florida: A Community Profile*. Biological Report 85 (7.25). U.S. Department of the Interior, Fish and Wildlife Service, Washington, D.C. 155 pp.

Appendix D
INVENTORY OF FRESHWATER BIOTA FOR THE SOUTH FLORIDA WATER MANAGEMENT DISTRICT ISOLATED WETLAND MONITORING PROGRAM

S. Mortellaro
South Florida Water Management District

SUMMARY

The development of hydrologic criteria for isolated wetland protection is a key element in implementing water supply plans and water use permits. A monitoring and evaluation program is being developed to accomplish the following:

1. Evaluate present drawdown criteria
2. Establish cause-and-effect relationships between South Florida Water Management (District) permitted hydrologic activities (e.g., ground water withdrawal, surface drainage) and adverse ecological changes in isolated wetlands
3. Recommend hydrologic criteria for future rulemaking

A review by District staff and a District-sponsored panel of experts concluded that the present technical literature contains insufficient information for satisfying these objectives, and recommended that the District implement a monitoring program focusing on biological indicators of wetland function and health. Wetland study areas located throughout the District have been selected for this project. Two study areas are adjacent to active municipal wellfields (Lee and Martin counties) and include several isolated wetlands located at varying distances from the center of the wellfield drawdown cone. Regional reference wetlands have also been established in large relatively undisturbed natural areas (Martin, Osceola, and Polk counties).

As part of this project, a pilot study is planned to collect quantitative data needed to characterize spatial and temporal variability of indicator species and to compare different sampling and collection techniques. Prior to beginning this pilot study, however, it is necessary to determine what species inhabit the wetlands selected for the project and which of those species are most promising as indicators of hydrologic stress. Preliminary work reviewed in this discussion has identified several broad classes of potential indicator organisms, which include amphibians, birds, bryophytes, fish, macroinvertebrates, algae, and vascular plants.

The objectives of these studies were as follows:

1. Conduct an inventory of amphibians, birds, bryophytes, fish, macroinvertebrates, algae and vascular plants in isolated wetland habitats within the South Florida Water Management District (SFWMD)
2. Evaluate sampling methods to identify effective means of monitoring the biota within these habitats
3. Conduct a literature review to identify and summarize life history information of the targeted biota known to occur in South Florida
4. Develop recommendations for using these organisms as indices of aquatic environmental health in isolated wetlands

ALGAE

Rosen and Mortellaro, 1998

Algal communities have been identified as a potential group of organisms that may show promise as an indicator of hydrologic stress or ecological condition. An inventory of the algal communities found in selected isolated wetlands of South and Central Florida was conducted. The collection effort focused on the outer edges of the water/soil interface and included the soil-adapted forms adjacent to the wetland. A total of 59 genera were found. Of these genera, only one *Microspora* may be considered as an indicator of hydrology. The other genera were present because of their preference for soft or acid conditions. Specimens analyzed were photographed.

AMPHIBIANS

Donnelly, 1997

The results from the preliminary survey indicate that amphibians can be sampled using standard methods in isolated wetlands. Most of the amphibian species found in counties of the SFWMD have a complex life cycle wherein eggs are deposited in water (either attached to submerged vegetation, on the surface, or in mud nests), eggs hatch into a larva, the larva undergoes metamorphosis, and enters the terrestrial ecosystem. Exceptions to this include the direct developing forms (amphibians that deposit eggs in terrestrial sites and hatch as miniature adults) and totally aquatic forms (sirens, dwarf sirens, and amphibians). With the exception of two species of amphibians characterized by direct development, all amphibian species encountered during this study would be indicators of hydrologic change because of their dependence on water or very wet habitats for successful reproduction. However, many scientists suggested that decline in amphibian populations around the world are an indication of general environmental degradation. A two-year study is proposed because amphibians are long-lived ectothermic vertebrates that are strongly affected by climatic conditions. Proposed sampling of larvae and adults is by using standard methods on a monthly basis. Larvae will be sampled with throw traps and standard D nets and/or with traps constructed from large diameter sewer pipe (PVC). Adult sampling using visual encounter surveys along transect lines established in each selected wetland would be employed. The sampling of completely aquatic species (e.g., sirens or amphibians) cannot be accomplished with visual encounter surveys therefore; baited funnel traps will be used.

BIRDS

Mahoney, 1997

Wading birds rely on a network of wetlands, both large and small, for breeding and foraging. Wading birds use isolated wetlands because they support a diverse assemblage of prey species that is uniquely different to those found in larger more permanent bodies of water. They require fluctuating water levels to concentrate prey, they respond quickly to fluctuations, and their distribution is a reflection of temporal and spatial variability in hydrological regimes and breeding sites. Guilds of wading birds can be identified based on usage of isolated wetlands (obligate or facultative) and prey size and hydroperiod preferences.

A remote monitoring method was tested to determine the feasibility of the using of a fixed camera to identify and census wading birds. The method appears to be a reliable and relatively inexpensive means of monitoring the presence of wading birds.

BRYOPHYTES

Glime et al., 1997

Bryophyte responses to desiccation differ in several ways from those of vascular plants. The response of vascular plants to drought is mainly through a change in the species composition, a community response. Bryophytes, on the other hand, respond to change in hydrology at both the individual and community level. Mosses lack many of the strategies to escape desiccation that benefit vascular plants. They cannot make use of deep roots (they have no roots) or increase the length of their subterranean component (rhizoids). Desiccation tolerance depends on the physiological state of the moss, and this varies with the season. The literature is of little value in determining the hydrologic indicator value of any of the bryophytes collected in the SFWMD. Bryophytes occupy areas on a microscale over several consecutive years or even decades. Thus, they are able to integrate the effects of the environment, including the effects of an altered hydrologic regime. Furthermore, the bryophyte species in the cypress dome areas are present year round and bryophytes usually suffer little herbivory, making them ideal monitoring organisms.

The most important taxa in the wetland habitats inspected are the *Sphagnum* species and the taxa present in the "moss collars." The latter include *Isopterygium tenerum*, *Syrrhopodon texanus*, *Leucobryum albidum*, and *Octoblepharum albidum*. In addition, *Porella pinnata* may be important in some sites because it is a typical high-water bryophyte in some of the more northern cypress swamps in Florida. A study of the thallose liverworts *Riccia* and *Riccardia* responses to flooding and drying would be valuable both biologically and as assessment tools for monitoring hydrologic changes.

Recommended monitoring efforts are to determine the reinvasion of moss collar species, determine the ratio of coverage of liverworts to mosses, conduct reciprocal transplant studies, establish permanent quadrates for the four major taxa, compare competitive abilities of the major taxa, document any morphological differences in leaves and stems of *Sphagnum* species and determine their annual growth rate, examine the flooding effects on the floodplain species, and map the distribution of the *Campylopus*.

FISH

Main et al., 1997

Fish communities provide a potential index to the effects of water drawdown on the environmental health of isolated wetlands. Interpretations of wetland hydrology from fish community data may best be done by evaluating the presence of species from different functional groups. The functional fish groups defined in this report represent a progression from species that inhabit temporary to seasonal (ephemeral) wetlands (Group I and II), to semi-permanent wetlands (Group III). Species richness, relative abundance, and the proportion of fish biomass that occur within these functional groups are informative measures of wetland conditions and hydrological patterns. Therefore, it is recommended that Breder traps (or similar traps) should be used in conjunction with dip nets for collecting fish in Functional Groups I and II. For collecting larger fish in deep wetland pools (Functional Group III), it is recommended to experiment with non-destructive methods such as hoop nets (Fyke nets), throw traps (Wegener ring) and cast nets. Because seasonal fluctuations in hydrology influence fish community structure, the monitoring regime should incorporate a temporal sampling component to ensure changes in fish community structure can be correlated to hydrological patterns. To accomplish this, sampling should be conducted a minimum of three times per year in control areas and possibly more in areas where premature drydown related to water use may occur. Fish community structure should be assessed as follows:

1. Early in the wet season following heavy rainfall events
2. Mid-late wet season when fish have colonized available wetland habitats
3. Mid-late dry season when drawdown has concentrated fish in pools or semi-permanent hydroperiod wetlands

This sampling regime should be continued for a minimum of two to three years unless climatic conditions warrant additional sampling.

MACROINVERTEBRATES

Stansly et al., 1997

The results of the macroinvertebrate study and the few studies that have examined impacts of drawdown suggest that one beneficial avenue of future research would be the analysis of voltinism (number of generations per year) among Chironomid species as well as their ability to enter into cryptobiosis (ability to enter into an inactive or quiescent state). Unfortunately, there are no studies that have examined voltinism among chironomids in South Florida. As a result, suggestions of appropriate species as indicators could not be made. However, this study suggests that those assemblages with higher proportions of large chironomid predators (primarily Tanypodinae) are less impacted by fluctuating water levels and that a fruitful index might be the ratio of predators (Tanypodinae) to detritivores/herbivores (Orthocladinae + Chironominae). Another possible avenue suggested by the results would be to focus on the anisopteran odonates, in particular the Aeschnidae, as a long-lived group totally dependent on water for survival of immature stages which are relatively easy to collect with a dip net and to identify to genus with a hand lens. Nondestructive sampling techniques for non-chironomids macroinvertebratres should include the use of Breder traps and dip nets. The sampling should be conducted at each location for a period of approximately two hours. Since Breder traps are generally biased against the Chironomidae, sampling for this group included artificial substrate (constructed from 6 centimeter (cm) diameter bottle brushes with the handle imbedded in a small cup containing concrete) and dip nets sampling the bottom material, macrophyte stems and leaves and the surfaces of submerged logs and stumps. It is recommended that sampling occur four times a year (once each season) and results compared to sites of known hydrology.

VASCULAR PLANTS

Bridges, 1995

Plants species responses to hydrologic change is a very complex process. This is important because there are pronounced differences in rainfall between the summer wet and winter dry seasons, with high potential evapotranspiration throughout the year in South and Central Florida. Given this wide natural fluctuation in hydrology in natural, undrained wetlands, determining the effects of man-induced change can be extremely difficult except in the most extreme cases. In the analysis of species change from year-to-year or from season-to-season, the variation in the natural hydrologic regime must always be considered as the most obvious potential cause. Natural variation or causes must be considered when explaining changes in vegetation patterns by man-induced changes to hydrology. A natural drought can produce similar responses in plant community composition and structure for drained and undrained wetlands.

Anderson, 1997

There is difficulty in identifying indicator species of ground water drawdowns for the following reasons:

1. Plants may react similarly to man-made drawdowns as to natural droughts
2. Some wetland plants are very tolerant of prolonged dry periods
3. Discomparate floristic composition among the regions a “universal” indicator species can not be used

However, indicator species might best be selected from short-lived (non-woody nor rhizomatous) wetland plants that tend to diminish in numbers or moving further into the wetland through seed dispersal. To more fully understand the floristic communities, two additional surveys are recommended (April or early May and August or September). These surveys are needed to properly access the total floristic composition because the three completed (November, February-March and June) are spread far enough apart temporally that fast growing species could have grown, bloomed, and senesced before the next survey. To monitor plant population, it is recommended that quadrates be established to conduct qualitative and quantitative measurements. A 1 meter-by-15 meter (m) plot could be laid out monitored at the 5 m and 10 m intervals.

The recommendations provided in these reports are preliminary in scope and additional studies to verify or modify these recommendations will be needed prior to the development of reliable management policies.

REFERENCES

Anderson, L.C. 1997. *Inventory of Freshwater Plants for the Isolated Wetland Monitoring Program*. South Florida Water Management District, West Palm Beach, FL.

Bridges E.L. 1996. *Inventory of Freshwater Vascular Plants for the South Florida Water Management District Isolated Wetland Monitoring Program*. South Florida Water Management District, West Palm Beach, FL.

Donnelly, M.A. 1997. *A Preliminary Survey of Amphibians in Isolated Wetlands*. South Florida Water Management District, West Palm Beach, FL.

Glime, J.M., A.L. Bauhhuber, T.S. Barbour and J.K. Marr. 1997. *Inventory of the Bryophytes for the South Florida Water Mangement District's Isolated Wetlands Monitoring Program*. South Florida Water Management District, West Palm Beach, FL..

Mahoney, S.A. 1997. *Isolated Wetland Monitoring: Freshwater Birds*. South Florida Water Management District, West Palm Beach, FL.

Martin B.M., D.W. Ceilley and P.A. Stansly. 1997. *Inventory of the Freshwater Fish for the South Florida Water Mangement District's Isolated Wetlands Monitoring Program*. South Florida Water Management District, West Palm Beach, FL.

Mortellaro, S.M. 1998. *Quantifying Vertical Vegetative Structural Changes in Isolated Wetlands*. South Florida Water Management District, West Palm Beach, FL.

Rosen, B. and S.M. Mortellaro. 1998. *Inventory of Freshwater Algae for the South Florida Water Management District's Isolated Wetlands Program*. South Florida Water Management District, West Palm Beach, FL.

Smock, L.A. 1995. *Characterization of Macroinvertebrate Communities in Isolated Wetlands of South Florida*. South Florida Water Management District, West Palm Beach, FL.

Stansly P.A., J.A. Gore, D.W. Ceilley and M.A. Main. 1997. *Inventory of Freshwater Macroinvertebates for the South Florida Water Management District Isolated Wetland Monitoring Program*. South Florida Water Management District, West Palm Beach, FL.

Appendix E
VALUED ECOSYSTEM COMPONENT (VEC) OF THE CALOOSAHATCHEE RIVER/ESTUARY: A PRELIMINARY ANALYSIS OF THE LITERATURE RELATED TO THE BIOLOGICAL STUDIES

S.A. Bortone and R.K. Turpin
Florida Center for Environmental Studies

INTRODUCTION

The concept of the Valued Ecosystem Component (VEC) is considered essential to the integrated management and monitoring of ecosystems. The VEC is an approach to aid Okeechobee Systems Research Division's goal to "Protect and Enhance Estuarine Ecosystems". The concept behind the VEC was developed by the United States Environmental Protection Agency (USEPA, 1987) as part of its National Estuarine Program and subsequently adopted by the South Florida Water Management District (SFWMD) to help attain its overall management goal for estuaries under its jurisdiction. The premise behind a VEC approach is to manage an estuary for key species or groups of species. Key species are those that comprise the ecological structure and define the function of that predominate in estuarine communities. Similar to a biocenosis, these key species provide food and/or habitat for a preponderance of the community and form an important, if not critical, link for the entire estuarine associated assemblage of organisms.

The Caloosahatchee River/Estuary on Florida's lower west coast has had a long history of manipulation by human activity, much of this coming under the auspices of flood control as part of a conduit from Lake Okeechobee. While this manipulation has not necessarily been detrimental to the estuarine community, it certainly has had a profound affect on the salinity regime of the entire lower west coast, including its nearshore estuarine waters.

Maintaining the condition of the Caloosahatchee River/Estuary is a prime objective of the SFWMD ecosystem management strategy. Importantly, to accomplish this task, an overall measure of its condition must be in place. The VEC is clearly one way to accomplish this task. However, prior to the implementation of any VEC, the key species must be identified. Since each estuarine ecosystem is a unique mixture of organisms, it stands to reason that the key, VEC species for a given area may be different for each region. Additionally, any monitoring study can benefit significantly if it can make use of the information available from previous studies. These data can help expand the scale (both in terms of time and space) of the evaluation, and also give an essential perspective of long-term trends that may be masked by short-term perturbations.

Hence, our purpose here is to survey the literature to identify past studies that have substantial information on the biological aspects of local estuarine species. Moreover, this literature survey can help identify, through the expert vision of past researchers, those species that are likely to serve as key species. Once this literature is identified and annotated, it will be possible (with greater certainty) to identify the key species upon which to base a VEC approach to estuarine ecosystem management. Once identified, an assessment plan can be developed to fully define the limits and extent of these VEC components.

The purpose of the study presented herein is to conduct a review of the readily available literature on the biological studies that have been conducted in the Caloosahatchee River/Estuary and its immediate surroundings. The objective of this review is to identify organisms or groups of organisms that should be included as members of the VEC.

The results of our efforts are present below. This study serves to identify the literature and evaluate their contents. This will help guide the decision making process in choosing the species or species groups for a VEC approach to ecosystem management in the Caloosahatchee River/Estuary.

MATERIALS AND METHODS

With the cooperation and expert assistance of the library staff at Florida Gulf Coast University (FGCU) we had access to the majority, but certainly not all, of the readily available literature (both published and unpublished) related to biological assessment studies conducted on the fauna and flora of the waters associated with or proximate to the Caloosahatchee River/Estuary.

With the help of the FGCU library staff, we identified the literature that was related to the topic of biological assessment in the area. Titles of each article were read for an indication that information specific to our purpose was potentially included. Not all articles concerning the environmental conditions of the Caloosahatchee area were useful to us. For example, many articles were on the geological features of the area or, if biological, were terrestrially oriented. This subset of articles was read, when available, for specific details that would permit an evaluation of their contents and utility toward our goal. Each article was read for information that would enable us to evaluate the extent, groups, methods, and scale (both time and space) that was covered. This information, plus identifying information, conclusions of the work, and a summary evaluating each article's usefulness are given herein.

RESULTS

On the following pages, please find annotations for literature that was examined as part of this evaluation.

Author: Bierman, V.J., Jr.

Date: 1993

Title: *Performance Report for Caloosahatchee Estuary Salinity Monitoring*

Citation: Report prepared for the SFWMD. SFWMD expert assistance contract deliverable. Limno-Tech, Inc. Ann Arbor, Michigan.

Purpose: To describe the salinity distributions in the Caloosahatchee Estuary in response to different levels of freshwater inflow. The report includes a description of the water quality model used in the study, a description of the spatial domain of the system divided into 23 segments, and the specifications for the specific model inputs.

Geographic extent: Covers the Caloosahatchee River from S-79, downstream to the River mouth at Mark-H where the salinity recorder is located.

Groups covered: No biological groups, but extensive salinity references.

Sampling method: N/A

Gear: N/A

Spatial scale: N/A

Temporal scale: N/A

Associated data: Salinity modeling data and metadata.

Conclusions: (taken from the summary) The Caloosahatchee River and Estuary connect Lake Okeechobee to the Gulf of Mexico. Freshwater inflow releases from Lake Okeechobee can have a significant impact on salinity in the Caloosahatchee Estuary. Excessive freshwater discharges can reduce salinity levels, while zero discharges may cause hypersaline conditions. Both oligosaline and hypersaline conditions can stress the estuarine flora and fauna (Scarlatos, 1988).

The objective of this study is [was] to develop a water quality model to predict Caloosahatchee Estuary salinity in response to a range of freshwater flow conditions. The water quality model WASP4 was applied to the Caloosahatchee Estuary from Franklin Lock and Dam to Pine Island Sound to meet this end. The model was calibrated to one year (1992) of data from four continuous monitors located throughout the estuary. Model calibration consisted of selection of appropriate tidal dispersion coefficients. The calibrated model was capable of describing approximately 90 percent of the observed variability in Caloosahatchee River salinity. The model is better suited to describe Caloosahatchee River response to long-term average inflows than for short-term event flows.

Once calibrated, model projections were run to predict the spatial distribution of salinity to a series of steady state freshwater flow releases ranging from 0 to 6,000 cfs. These projections indicate that for the low flow scenario, salinities over 32 ppt (parts per thousand) can be observed throughout the entire study area. For the highest flow scenario, salinities are predicted to be less than 2 ppt for all but the lowest 2 kilometers (km) of the estuary.

Summary: This paper contains no biological information but does contain important model information with regard to salinity. The paper was clearly one of the most influential in directing the tape grass research and serves as a foundation for future research, especially with regard to choosing sample site locations.

Author: Chamberlain, R.H and P.H. Doering

Date: no date

Title: *Freshwater Inflow to the Caloosahatchee Estuary and the Resource-Based Method for Evaluation*

Citation: Draft, in-house report to the SFWMD.

Purpose: To provide an overview of the Caloosahatchee Estuary and River with regard to a site description (i.e., the important physical and hydrologic features), the potential for environmental problems associated with extremes in high and low freshwater inflows, and a description of the SFWMD resource-based strategy for establishing a suitable salinity range for a healthy ecosystem.

Geographic extent: Covers the Caloosahatchee River and Estuary.

Groups covered: Comments on the impact on tape grass are included along with mention of the other grasses (i.e., *Halodule*), mangroves, oyster bars, and scallops. Indications in the text indicate sampling has been conducted for bottom invertebrates, SAV, plankton (including larval fish and algae), and water quality under various conditions of freshwater inflow and salinity since 1986.

Sampling method: No specific sampling method is outlined or presented. Mention is made of field sampling and laboratory experiments to determine the salinity tolerances of tape grass.

Gear: N/A

Spatial scale: N/A

Temporal scale: N/A

Associated data: Map of the sampling sites, a chart of the flow categories, graph of the discharge levels for the basin and total drainage (including averages for 1966-1994 and specifically 1995) salinity profiles by month at locations along the estuary, hydraulic resident times, and a graph of the salinity tolerance zones for tape grass and oysters and seagrass in the estuary relative to location along the river.

Conclusions: (taken from the abstract) The Caloosahatchee is the major source of freshwater for the Caloosahatchee Estuary and southern Charlotte Harbor aquatic environment. Development of an intricate system of canals within the watershed, in conjunction with regulatory discharges from Lake Okeechobee, has resulted in a drastic alteration in freshwater inflow to this ecosystem. The resulting large fluctuations of salinity and water quality can adversely impact estuarine biota. This paper describes the following:

1. important physical and hydrologic features of the Caloosahatchee Estuary and the potential environmental problems associated with extremes of high and low freshwater inflows

2. the SFWMD resource-based strategy for establishing an optimum distribution for freshwater inflows (quantity) in order to provide a suitable salinity range (envelope) for a healthy ecosystem.

Summary: This paper is an excellent brief overview of the situation and status of the ongoing SFWMD research efforts in the Caloosahatchee Estuary. While no data were supplied in the document, several summary graphs are presented which give important relevant information on the potential relationship between salinity, freshwater inflow, and tape grass, oyster, and seagrasses. A good starting point. The main purpose here was an overview.

Author: Doering, P.H. and R.H. Chamberlain

Date: no date

Title: *Water Quality in the Caloosahatchee Estuary, San Carlos Bay, and Pine Island Sound, Florida*

Citation: Report to the SFWMD.

Purpose: (from the paper) To summarize water quality conditions in the southern portion of the Charlotte Harbor system, describing seasonal and spatial variation in water quality and comparing water quality with other established standards that are more generically applied. While this assessment does not set goals for water quality, it should provide a context for evaluation of the system's existing condition.

Geographic extent: Includes the southern portion of the Charlotte Harbor system, the Caloosahatchee Estuary, San Carlos Bay, and Pine Island Sound (map included).

Groups covered: No organisms are covered in this report.

Sampling method: N/A

Gear: Van Dorn bottle

Spatial scale: depth of 0.5 meters (m)

Temporal scale: At slack high tide (i.e., high tide) monthly for all stations from 1985-1989 and only stations 0, 2, 4, 8, 10, 11, 12, 16, and 17 from 1994-1995.

Associated data: Summary and metadata at 17 stations for salinity, dissolved inorganic nutrients (NH_4, NO_X, NO_2, PO_4) and color. Additionally, total Kjeldahl nitrogen (TKN), total phosphorous (TP), total suspended solids (TSS), turbidity, and chlorophyll *a* were analyzed. At 0.5-m depth intervals at each station, temperature, dissolved oxygen, and salinity were recorded.

Conclusions: (taken directly from the Abstract) Concentrations of nutrients and other water quality parameters were sampled monthly at 17 stations in the Caloosahatchee Estuary/Pine Island Sound region of the Charlotte Harbor system from November 1985 to May 1989. Several of these stations were revisited on a monthly basis from November 1994 to December 1995. Compared to other Florida estuaries, median concentrations of Chlorophyll *a* and total suspended solids were relatively low, while median concentrations of dissolved oxygen, total nitrogen, and color were relatively high. Turbidity and the concentration of total phosphorous were close to median values for other Florida estuaries. Concentrations of most parameters were higher in the Caloosahatchee Estuary than in San Carlos Bay or Pine Island Sound. Total suspended solids showed the opposite pattern, being higher in the Sound and Bay than in the estuary. Although dissolved oxygen concentrations generally were high in the overall system, some values at or below 2 milligrams per liter (mg/L) were observed at the head of the Caloosahatchee Estuary. These instances of hypoxia occurred mainly between May and October.

Summary: This paper summarizes the sampling effort and results of water quality at 17 stations in the Caloosahatchee Estuary area. No biological data were presented except for chlorophyll *a* and perhaps DO. The data are relevant to future sample and study designs.

Author: Drew, Richard D. and N. Scott Schomer

Date: 1984

Title: *An Ecological Characterization of the Caloosahatchee River/Big Cypress Watershed*

Citation: U.S. Fish and Wildlife Service FWS/OBS-82/58.2. 225.

Purpose: This report is a review and synthesis of the available literature relating to the region.

Geographic extent: Large area including: Caloosahatchee River Watershed, Estero Bay Watershed, and Big Cypress Watershed.

Groups covered: (Chapters) Geology and physiology, climate, hydrology and water quality, watershed energetics, plant communities, fauna.

Sampling method: N/A

Gear: N/A

Spatial scale: N/A

Temporal scale: N/A

Associated data: N/A

Conclusions: (page 60- Tidal Caloosahatchee River) Channel depth and bottom configuration descriptions; river dimensions, etc. Below the Highway 41 Bridge, the river bottom north of the channel is a broad, shallow shelf.

(page 61) In a detailed study of salinity, DeGrove (1980) was unable to demonstrate a convincing agreement between observed and calculated isohalines along the length of the estuary from Fort Myers to Shell Point. Water masses frequently appear oriented in a direction opposite to that predicted, suggesting that movement patterns are much more complex than the model was able to depict.

(pages 62-64) Water quality parameters (DO, temperature, CBOD, chlorophyll a) are discussed. Five sources of water pollution are identified: flow from Franklin Lock, Orange River, Fort Myers sewage treatment plants, Cape Coral subdivision and sewage treatment plant, and Waterway Estates sewage treatment plant.

(page 123) ...the benthic community is either a marine grass-covered bottom or an open bottom composed of varying mixtures of sand, mud, oyster shell, and bedrock. Benthic community is influenced by salinity, bottom type, water depth, and currents… [They are] in a state of flux.

(pages 124-127) Seagrasses thrive only in the least disturbed bays and estuaries. Relatively high turbidity and color, and periodically reduced salinities may be natural factors which limit the distribution of seagrasses. The effects of human activities on seagrasses are also discussed. Seven species of rooted vascular plants and 46 algal taxa are referenced from Phillips and Springer (1960). In terms of total community metabolism, depth-specific measurements suggest that the benthic macroflora and microflora may account for as much as 65 to 85 percent of the metabolism in shallow waters such as Estero Bay. Nutrient loading, salinity, turnover time, sediment composition and chemistry, depth, and bottom topography are listed as possible influences (singly or in combinations) that may affect benthic community composition.

(page 146) The two major studies on invertebrates for the Caloosahatchee River estuary are: Gunter and Hall (1965) and Applied Biology (1976). Gunter and Hall could not differentiate between the benthic and planktonic components of the samples because trawls were used.

(page 148) BENTHOS: Variation within the estuarine and marine benthic invertebrate community is primarily controlled by substrate (grain size and composition) and salinity. Other major factors that influence community composition are water temperature, plant cover, disruptions,… predator-prey interactions, and food availability. Physical activities of the organisms ("bioturbation") also have effects and are affected by DO.

(page 149) Substrate differences that most clearly delineate benthic communities from one another are the hard and soft bottoms, and the intertidal and submerged bottoms. A change occurs in species composition and abundance from the vast middle-ground area between San Carlos Bay and Franklin Locks where salinity fluctuates greatly (no reference).

INTERTIDAL COMMUNITIES: The four major types of intertidal communities in the region are: prop-root associates of red mangroves; oyster reef; intertidal mud flats; and seawall communities. The temporal and spatial variation in species composition among communities are largely dependent on salinity, DO, substrate, flow and tides.

(page 151) SUBMERGED BOTTOMS: Decapod crustaceans comprise one of the most important groups of invertebrates that characterize the estuarine floor'' (species are listed also). The pink shrimp and stone crab, because of commercial value and role in benthic ecosystem, are discussed in length.

(page 160) FISHES: Brief summaries of 11 families occurring in freshwater are given (pages 163-6). Factors affecting the composition of the freshwater fish community in Southwest Florida are fluctuating water levels, predation, geographic location and habitat alteration.

(page 168) ESTUARINE FISHES: Marine and estuarine fishes of Southwest Florida have been grouped into four community types based on salinity, detritus and substrate. (Odum et al, 1982). These are black mangrove basin forest, riverine fringing community, estuarine bay fringing community, and oceanic bay fringing community. Descriptions of these communities follows (pages 169-175) and includes species occurrences and ecological parameters.

Summary: This is an excellent and fairly recent (1984) summary of information. Although not a scientific study, this publication is one of the most thorough reviews of the region.

Author: Estevez, E.D.

Date: 1981, revised 1984

Title: Pine Island Sound and Matlacha Pass

Citation: In: *A Review of Scientific Information: Charlotte Harbor Estuarine Ecosystem Complex*. Report to the Florida Regional Planning Council. Volume II, Chapter. VI. pp. PM-1 to 95.

Purpose: This two volume report is a review of the published and unpublished scientific literature on the Charlotte Harbor estuarine ecosystem complex. The specific purpose is to:

1. Compile information on these areas as a ready reference for local, regional, and state governments
2. Develop the first composite descriptions of the Peace River, and the Charlotte Harbor complex of estuaries
3. Identify information needs useful in resource management and provide recommendations for future study

Geographic extent: The entire project covers the Charlotte Harbor estuarine complex which includes Gasparilla Sound, Peace River, Charlotte Harbor, Pine Island Sound and Matlacha Pass, and San Carlos Bay. The Pine Island Sound and Matlacha Pass are of more immediate interest to this examination.

Groups covered: Biologically there are descriptions of the terrestrial flora of the local drainage system. Also included are descriptions for the marine vegetation of the waters. Faunal descriptions include information on benthos. A rather extensive list of bibliographic references indicates that most surveys provide only checklists for the various groups present. It appears that mollusks have been the most studied of any group in this area owing to both their recreational and commercial value. Brief mention is made to references dealing with fishes, turtles and terrestrial vertebrates. A model for the entire ecosystem of the Matlacha Pass is duplicated from a previous study (EcoImpact, 1973).

Sampling method: Not applicable as this paper is a summary of existing literature.

Gear: N/A

Spatial scale: N/A

Temporal scale: N/A

Associated Data: N/A

Conclusions: N/A

Summary: N/A

Author: Estevez, E.D.

Date: 1981, revised 1984

Title: San Carlos and Estero Bays

Citation: In: *A Review of Scientific Information: Charlotte Harbor Estuarine Ecosystem Complex*. Report to the Florida Regional Planning Council. Volume II, Chapter VII. pp. S-1 to 149.

Purpose: This two volume report is a review of the published and unpublished scientific literature on the Charlotte Harbor estuarine ecosystem complex. The specific purpose is to:

1. compile information on these areas as a ready reference for local, regional, and state governments
2. develop the first composite descriptions of the Peace River and the Charlotte Harbor complex of estuaries
3. identify information needs useful in resource management and provide recommendations for future study

Geographic extent: The entire project covers the Charlotte Harbor estuarine complex which includes Gasparilla Sound, Peace River, Charlotte Harbor, Pine Island Sound and Matlacha Pass, and San Carlos Bay. The area of San Carlos Bay and Estero Bay are the focus of the reports below.

Groups covered: Terrestrial flora references and descriptions are presented. Water column productivity is summarized. A detailed summary of the benthos is offered with descriptions of the sample locations as well as a species list and some estimates of species or higher taxa abundance. Fish references include summary information from Gunter and Hall (1965). An ecosystem model produced for the regional planning council is presented.

Sampling method: Not applicable as this paper is a summary of existing literature.

Gear: N/A

Spatial scale: N/A

Temporal scale: N/A

Associated Data: N/A

Conclusions: N/A

Summary: N/A

Author: Estevez, E.A.

Date: 1986

Title: *Infaunal Macroinvertebrates of the Charlotte Harbor Estuarine System and Surrounding Inshore Waters, Florida*

Citation: U.S. Geological Survey, Water Resources Investigations Report 85-4260. Tallahassee, Florida.

Purpose: To describe existing conditions and evaluate the impact of future development on the estuary. Focus was on the relationship between hydrodynamics and water quality, and more specifically, on the macroinvertebrate fauna and the soft bottom environments of the Charlotte Harbor region. Details the sampling methods of a survey conducted in 1980. It provides a list of the infaunal macroinvertebrates from soft bottom habitats; assess the suitability of the sampling methods; and identifies the spatial and seasonal trends or patterns in the benthic communities and relates them to environmental conditions. The survey was limited to unvegetated, soft-bottom habitat.

Geographic extent: Survey included the Charlotte Harbor area from the Peace and Myaka rivers, the Harbor, Pine Island Sound, Matlacha Pass, Sanibel, San Carlos Bay, Estero Island, and the major passes to the gulf.

Groups covered: A total of 546 species including 15 phyla. Annelids were most specious (197 species), followed by mollusks (156 species), arthropods (133 crustacea and five insects). Ninety percent of the species were from these three phyla. The complete faunal list is given.

Sampling method: N/A

Gear: Intertidal samples were collected with a 7.62-centimeter (cm) diameter core to a depth of 15 cm. Cores were closed at the top with a 0.5-millimeter (mm) mesh screen. Five samples were taken at each site (total sample area was 0.114 m^2). Subtidal samples were taken with petite Ponar grab sampler (0.022-m^2 area). Five grabs were separately washed through 0.5-mm mesh screen. Total sample area was 0.112 m^2.

Spatial scale: A total of 25 stations were sampled (11 intertidal, 14 subtidal). Depth range was 0.3 to 0.8 m for intertidal samples and 1.7 to 4 m for subtidal sites. Sites were in rivers (3, Myaka; 2, Peace); sounds (10), channel entrances (6); and just into the gulf (2).

Temporal scale: Stations were sampled twice a year for one year. Subtidal stations were sampled on 15 May 1980 and 16 September 1980. Intertidal stations were sampled on 16 June 1980 and 16 September 1980.

Associated data: Sediment samples were taken (2-5 cm diameter plugs to 10 cm) and analyzed for characteristics (grain size; silt:clay fraction, organic content). Other variables: temperature, depth, conductivity, DO at surface and bottom.

Conclusions: (quoted directly from the paper) The first major objective of this investigation was to survey macroinvertebrate infauna of the dominant bottom environment of the study area, namely the unvegetated sandy benthos.

Collections during May through September 1980, a water year in which spring was wetter and summer was drier than normal, produced 546 species of marine and estuarine invertebrates in 15 phyla. This list is larger than previously available for all benthic environments in the area but probably understates maximum diversity since no samples were taken in winter or from either the Caloosahatchee River or Estero Bay.

The second objective was to assess sampling methods and locations. Because of Ponar grab spillage, manual coring was preferred over grabs, even in subtidal areas. Total sample area of 0.10 to 0.20 m^2 is probably adequate for most parts of the estuarine system. The deep transitional areas from Cape Haze to Punta Gorda, where anoxic conditions may be caused by stratification, will need larger sampling areas as well as many adjacent areas during summers of wetter years.

Intertidal sampling could be reduced and subtidal sampling increased, especially in the middle harbor area. Once hydrologic interactions between Pine Island Sound, Matlacha Pass, and San Carlos Bay are better known, additional stations would help document dynamics of their diverse infaunal communities. Having data on a station offshore Sanibel and Estero Islands would allow evaluation of shelf-estuary interactions.

The third objective was to identify patterns or trends in communities. Subtidal areas had more species than intertidal areas and changed more over summer, from higher to lower species numbers. Density ranged greatly. Subtidal densities decreased during summer, especially in upper harbor areas. Density in middle to lower harbor areas increased during the same period.

Sediment characteristics were more similar across the study area than hydrographic features. Trends in diversity and density corresponded to salinity and dissolved oxygen gradients and could be interpreted from both the observed and probable range and persistence of these gradients.

Most species were uncommon and numerically rare. Replacement of rare species was high between collections. Common species were often dominant. Combinations of these species occurred in areas of the estuarine system but in varying ratios. The roles of these species alone and in characteristic assemblages deserves attention. Overall, communities of the system are combinations of a broadly dispersed fauna rather than separate or coherent groups. Species number and density trended across the study area both latitudinally and longitudinally.

Similarity analysis revealed geographic clustering of mollusks and broadly dispersed assemblages of polychaetes and crustaceans. Mollusk groupings did not correspond to tidal position and both mollusk and crustacean similarity patterns distinguished Pine Island Sound from Matlacha Pass. Monitoring of harbor-wide subtidal areas would be feasible using only mollusks, whereas site specific analyses of polychaete or crustacean community structure would be helpful in assessing particular impacts of known origin.

Unvegetated sandy bottoms are the most common benthic environment of the Charlotte Harbor estuarine system and adjacent inshore waters and are populated by a rich macroinvertebrate infauna. Sediments of the area are structurally intact and relatively intact and relatively free of contaminants, except near residential canals and marinas so patterns of benthic diversity or density can be related to natural events with greater certainty than in less pristine estuaries.

New infaunal studies in the area should turn to the trophic role of key species (Word, 1980); the role of infauna in controlling events within overlying waters (Cloern, 1982); and the nature of infauna communities in natural areas (oyster reefs and seagrass beds) and areas affected by man (residential canals, navigation channels, and petroleum-contaminated sediments).

Summary: This is an extremely valuable reference. It provides data that are comprehensive spatially, although lacking somewhat in temporal considerations. It combines quantitative sampling of benthic infauna with a fair level of intensity of other environmental variables. Most importantly, it offers insight into the appropriate methods for sampling (both in actual protocol and general sampling design). The analysis gives some overall level of expectation of results on a broader or more comprehensive sampling effort. The suggestions offered by this paper should be carefully considered when designing any monitoring or assessment study in the general area.

Author: Fraser, T.

Date: 1981

Title: Variation in Freshwater Inflow and Changes in a Subtropical Estuarine Fish Community

Citation: In: Cross, R.D. and Williams, D.L. (eds.). *Proceedings of the National Symposium on Freshwater Inflow to Estuaries*, V.2, U.S. Fish and Wildlife Service, FWS OBS-8V04. pp. 296-320.

Purpose: This study addresses:

1. The relationship of fish abundance in Charlotte Harbor to freshwater inflow from the Peace River
2. Temporal variation in fish abundance
3. The relationship of fish abundance to other factors such as temperature
4. Long-term patterns in river flow and tidal flushing

Geographic extent: The study focuses on Charlotte Harbor but the interpretation of results are given on a broader scale to include the Apalachicola River estuary as well as to the even broader area between Tampa Bay and Estero Bay.

Groups covered: Fishes (including both Chondrichthys - sharks, skates and rays; and Osteichthys - bony fishes) are the subjects of this paper. Invertebrates were collected as part of the sampling method but the report comments only on the fishes captured.

Sampling method:

Gear: Eight two-minute repetitive 16-foot otter trawling was the main sampling device. The mesh on the net was 5/8-inch mesh in the lead panels and the bag to the trawl was 3/16 Ace mesh. Towing speed was at 1,100 rpm behind a 7.3-m long boat.

Spatial scale: Depths trawled were from 3.5-4.5 m at one location (26° 56.63'N; 82° 03.60'W).

Temporal scale: Nearly monthly sampling was conducted at night after twilight from 1975 to 1979.

Associated data: Fish abundance, catch rates as a total and by species, was the main reported and analyzed dependent variable. Water column was sampled at 0.5 m depth intervals at each station for temperature, salinity, DO, pH, and redox potential. River flow was reported from the Peace River and tides were used in the analysis.

Conclusions: (from the abstract and the conclusion sections) Trawl-susceptible fishes were sampled for five years in Charlotte Harbor, Florida. During this period, freshwater inflow recorded on the Peace River has varied from the second lowest to near the mean flow for the past 49 years. The 12 most abundant of 43 fish taxa captured, comprising about 98 percent of the total catch, were used in a detailed analysis with flow. Average seasonal abundance appeared to be inversely related to flow in the wet season and directly related to flow in the dry season. Strong correlations exist for flow in June and the average abundance for June through September, and also for December-January flows and the average abundance for December through May. Apparent cycles of flow with an average period of six years in each season. The wet season of 1977 may represent a minimum point in the wet season cycles. A predicted astronomic tidal effect with a period of 8.86 years reached a minimum in 1977. Relative abundance during the wet season of 1977 was higher than all other wet seasons and may have influenced abundances in the dry season of 1977-78.

Conclusions and recommendations for Upper Charlotte Harbor:

1. Yearly variation in river flow, particularly during the beginning of the wet season and near the end of declining temperature in the dry season, was correlated with fish abundance.
2. Extremely dry, wet seasons are accompanied by obvious increases in the abundance of very common fish species as well as the appearance of species not abundant during wetter seasons.
3. Changes in fish abundance during extremely dry, wet seasons may influence abundance in the following dry season.
4. Extremely cold temperatures can temporarily influence fish abundance and presence of taxa for short periods.
5. Long-term periodicity in river flow may average about six years for both wet and dry seasons. The amplitude in flows may be quite variable.
6. Coincidence of other regular long-term cycles such as tidal flushing may enhance environmental changes produced by fluctuating river flow.
7. It seems reasonable to expect some supra-annual oscillation in fish abundance related to changes in flow. The limits of variation are not clear, for the data only approach the known low-flow spectrum but are not even close to the known high-flow spectrum.

Conclusions: As presented in the publication as conclusions and recommendations for both Charlotte Harbor and Aplachacola.

1. At least some of the more common taxa in both estuaries show abundance patterns that are dissimilar in time. These differences could be an expression of the variation in the physical characteristics of the estuaries without implying significant genetic populational differences. Although, depending on life history patterns, this maybe one indication of major estuaries having distinct subpopulations such as described by Weinstein and Yerger (1976) for spotted seatrout.

2. Long-term periodicity in the flow of the Apalachacola River and the Peace River, while approximately similar in duration, may be the result of regional (local) climatic effects. Thus, it may be important to view general estuarine changes in periods much longer than the annual cycle to identify natural population oscillations from those resulting from man-made changes in flow.

Many of the observations for Charlotte Harbor, particularly in terms of the fish fauna, seasonal patterns of flow, long-term cycles may have analogues from about Estero Bay to Tampa Bay because of similar climatic and tidal conditions.

Summary: This paper gives an indication of the value of using fishes as a way of assessing the overall impacts of larger scale effects of freshwater inflow on a system. No reference site was established to permit a meaningful comparison, however. Data are given in sufficient detail on methods to allow one to conduct a study that could be directly compared with this study. Only one station was occupied but the major independent variables were measured during the sampling effort.

Author: Fraser, Thomas H.

Date: 1997

Title: Abundance, Seasonality, Community Indices, Trends, and Relationships with Physicochemical Factors of Trawled Fish in Upper Charlotte Harbor

Citation: *Bulletin of Marine Science* 60(3): 739-763.

Purpose: To determine relationships between freshwater inflow and (trawl-susceptible) fishes.

Geographic extent: Upper Charlotte Harbor Estuary

Groups covered: Fishes

Sampling method: Reciprocal tows were made using the four cardinal compass points, each tow timed for two minutes.

Gear: 4.9-m otter trawl and 1.58-cm mesh with 0.47-cm mesh liner in the cod end.

Spatial scale: 1.3 km^2 area in upper Charlotte Harbor near Charlotte Harbor Marker #1.

Temporal scale: Fish samples taken once per month during the first hour after twilight, from June 1975 through May 1988.

Associated data: Salinity, temperature, rainfall data, dissolved oxygen, color, and turbidity.

Conclusions: Monthly comparisons of fish populations were not very similar.

Anchoa mitchilli and *Cynoscion arenarius* were more abundant overall and during the wet season; *Symphurus plagiusa, Eucinostomus gula, Orthopristis chrysoptera,* and *Eucinostomus argenteus* were more abundant in the dry season. Long-term decrease in river discharge was considered an underlying cause for the abundance declines for *A. mitchilli* and *C. arenarius*. Longer periods of higher salinity and milder winters were considered reasons for the abundance increases for the less dominant, more subtropical species. Relative abundance of fishes was highest at dissolved oxygen levels of 2 – 4 mg/L. In the wet season, declining number of species generally coincided with declining salinities. The average number of fishes increased with decreasing salinities. Although relative total abundance increased with higher temperatures, separation of pure temperature response from salinity effects cannot clearly be shown. A Principal Components Analysis (PCA) yielded four factors which were further analyzed. Factor 1 (accounted for 34.7 percent of environmental variation) consisted of freshwater flow, water color, stratification, and salinity. Two groupings of fishes are identified and broadly fit a wet or dry season mode based on freshwater inflow, however, a majority of these groupings are based on juveniles and young-of-the-year specimens. Significantly lower freshwater inflow (higher salinity) over the long-term will lead to a more diverse less-dominant community different from that found in the upper harbor during typical wet seasons. The two most abundant species, *A. mitchelli* and *C. arenarius* were negatively affected by drier conditions.

Summary: All individual fishes in each tow were identified and counted; up to 100 individuals per species were measured for standard length. Eight measures of community aspects were also determined: total number of species, total number of individuals, standardized number of species, two species richness indices, two heterogeneity indices, and one equitability index. The PCA was used to extract composite variables or factors, however, freshwater flow was considered to be the ultimate factor of interest because it affects many important variables (e.g., salinity and dissolved oxygen).

Although the sampling area was in the northern portion of Charlotte Harbor, this project was a long-term fish community study that tried to determine linkage(s) with environmental conditions (especially freshwater flow). One possible weakness exists however; only one sample location was used.

Author: Gunter, G. and G. E. Hall

Date: 1965

Title: A Biological Investigation of the Caloosahatchee Estuary of Florida

Citation: *Gulf Research Reports* 21:1-71 (Also published as *Biological Investigations of Caloosahatchee Estuary in Connection with Lake Okeechobee Discharges through Caloosahatchee River.* A report to the District Engineer, Jacksonville District, USACE, May 1962).

Purpose: Review the history of the Caloosahatchee River and analyze the problems concerned with discharges into the estuary; present biological data from investigations of the estuary made at different times during the years 1957 to 1960, inclusive; determine the biological effects of operation of Moore Haven and Ortona locks, and the planned lock and dam at Olga with reference to important indicator species within the lower river and estuary.

Geographic extent: Caloosahatchee Estuary south of Beautiful Island and San Carlos Bay.

Groups covered: Fishes, benthic invertebrates, and aquatic vegetation

Sampling method:

Gear: 20-foot otter trawl with ½-inch bag mesh; 50-foot ¼-inch mesh beach seine (middle 25 feet of net backed with bobinet material); occasional supplemental seine drags taken with a 20-foot, ¼-inch mesh minnow seine.

Spatial scale: Trawl sample stations: eight within estuary, eight outside estuary; seine sample stations: eight within estuary, eight outside estuary.

Temporal scale: All stations sampled once every four months, from May 1957 through June 1960.

Associated data: Salinity (top and bottom), temperature, and freshwater discharge rates also recorded.

Conclusions: Fishes: marine species dominate, largest catches occurred in the estuary; higher quantities of fishes taken at the lowest salinities, mostly juveniles. Benthic invertebrates: Much higher numbers of species were taken from the higher-salinity waters of San Carlos Bay.

Summary: This study, although 30 years old, is spatially and temporally thorough. Trawl catches easily quantifiable (not true for seine collections).

Author: Morrison, D.

Date: 1989.

Title: *Ecological Assessment of the Cape Coral (Florida) Residential Waterway System*

Citation: Environmental Resources Division, Engineering Department, City of Cape Coral, P.O. Box 150027, Cape Coral, FL 33915.

Purpose: This report presents the findings and estuarine waterways in Cape Coral south of Pine Island Road. This study was designed to compliment and supplement SWFRPC (1984). It focuses on the environmental quality of the estuarine system, which is more developed and likely more impacted than the freshwater system; freshwater aquatic plant (macrophyte) ecology and management; and, the environmental impacts of bulkhead (seawall) constructions.

The information contained in this report, coupled with that in SWFRPC (1984), will serve as the basis for developing and implementing an aquatic resources management plan, which is required by the city's Comprehensive Plan. These findings will also serve as a baseline data to assess future environmental quality and to assess the effectiveness of any implemented management actions. This information may also assist in understanding and managing similar systems in Florida and elsewhere.

Geographic extent: Includes the entire Cape Coral waterway system south of Pine Island Road.

Groups covered: Freshwater macrophyte distribution and abundance was monitored along with a detailed study on the ecology of *Chara globularis*. Benthic invertebrates were sampled in the estuary for soft-bottom epifauna and infauna.

Sampling method: Sampling was conducted simultaneous with the water quality sampling effort. Overall sampling was conducted from 1986 to 1988. Specific groups below had more restricted sampling duration.

Freshwater macrophytes – Measures included estimates of abundance but no data were reported.

Gear: No sampling gear was indicated.

Spatial scale: Sampling was conducted at the 38 water quality stations.

Temporal scale: Monthly; 1 year for an intensive study, three years for a general study.

Chara – measures included photosynthesis, abundance, and reproductive condition.

Gear: Collected with SCUBA.

Spatial scale: Presumably taken with macrophytes. Twelve quadrates of 0.25 m^2 were sampled at each period.

Temporal scale: Presumably taken with macrophytes. Focus was in February, May, August, and November 1987.

Benthic invertebrates – No detail of the results were reported.

Gear: Ponar grab (0.025 m^2)

Spatial scale: Three locations in the estuary with 20 replicates at each station.

Temporal scale: No indication of how frequently.

Associated data: Water quality parameters included: temperature (S, M, B), salinity (S, M, B), conductivity (S, M, B), dissolved oxygen (S, M, B), turbidity (S, B), pH (M), ammonia (M), nitrate/nitrite (M), total Kjeldahl nitrogen (M), total phosphorus (M), orthophosphate (M), Chlorophyll total and *a* (M), and bacteria (S) at each of 38 locations in the study area, monthly. Sediment metal concentrations were sampled in 1988 at 12 selected stations. Analytes included: aluminum, arsenic, cadmium, chromium, copper, mercury, lead, tin, and zinc. Plankton productivity was measured in situ at two freshwater and three estuarine stations.

Conclusions: Two main habitat types occurred in the freshwater system:

1. High submerged macrophyte abundance
2. Low macrophyte abundance

Most canals were the former habitat. Water quality was generally good. Anthropogenic nutrients have appeared to enrich some areas and macrophytes have increased. The estuarine areas are more stressed. Flushing is poor. Benthic invertebrates and plants are more abundant in the natural system than in the estuarine canals. Poor light penetration may be a problem. The canals lack suitable habitat for animals. A comprehensive aquatic plant management plan should be developed. Bulkhead construction has a negative impact on benthic vegetation and benthic fish habitat. Wading birds are also negatively impacted by their construction.

Summary: A good study that covered many specific sites in a limited area. Data were collected and reported in detail. Time scale was limited to one year (1988). Conclusions and recommendations were reasonable but predictable based on a cursory inspection of the area. Interesting use of plant photosynthesis as a way of evaluating the condition of the vegetation but the specific objective for these measures were not explained.

Author: Phillips, R. C. and V. G. Springer

Date: 1960

Title: *A Report on the Hydrography, Marine Plants, and Fishes of the Caloosahatchee River Area, Lee County, Florida*

Citation: Florida State Board of Conservation. Special Scientific Report No. 5.

Purpose: Two groups were covered by this publication: Plants - to observe the immediate effects of fresh water on marine plants; Fishes - not stated, but assumed to be similar to purpose stated in plants section.

Geographic extent: Plants - Caloosahatchee River/Estuary south of the Edison Bridge, Matlacha Pass, San Carlos Bay, and Estero Bay. Fishes - Caloosahatchee River/Estuary, San Carlos Bay, and Estero Bay.

Groups covered: Plants and fishes.

Sampling method: Plants - box plant collecting dredge; Fishes - trynet.

Gear: Plants - box plant collecting dredge; Fishes - presumably only with a trynet.

Spatial scale: Plants - Caloosahatchee River south of the Edison Bridge, Matlacha Pass, San Carlos Bay, and Estero Bay. Fishes - Caloosahatchee River/Estuary, San Carlos Bay, and Estero Bay.

Temporal scale: Plants - 26-27 May 1958 and 12 Feb 1959; Fishes - two short periods, one each in 1958 and 1959.

Associated data: Temperature, salinity, and turbidity (Secchi depth).

Conclusions: Plants - 2 sampling efforts – 2,580 cfs of water was released during the initial sampling; no water was released for five months prior to the second sampling. Phillips concluded that algal species, especially small attached forms, were able to invade the Caloosahatchee River as the water release was suspended. Fresh water release did not seem to significantly affect growth of seagrasses…I cannot state that fresh water releases, at least in the amounts of 2,580 cfs or less, do any significant damage to plants in the Caloosahatchee River area.

Fishes - (from the article) In general, it can be stated that the fish fauna of the river was poor in numbers and species on both sampling occasions, and it was far exceeded by the fish fauna of the nearby higher saline waters.

Summary: This article is a combination of two separate studies, one on plants and one on fishes.

Plants - Samples were collected from twelve locations (listed above), giving a fairly thorough coverage of the area. Very little description of methods, therefore, it was neither reproducible nor quantifiable, except as categorically quantified (abundant, common, …) in the article. A total of 45 algal taxa and six species of aquatic flowering plants were found. The results give only an indication of which plants were present forty years ago.

Fishes - Nine locations within the lower Caloosahatchee River and one location just south of Punta Rassa were sampled. No description of methods. Fishes were identified to species, counted and measured. These data are only useful in terms of species presence.

Author: Morrison, D., C. Marx, P. Light, P. Renault, and J. Malsi

Date: 1989

Title: *Impact of Freshwater Discharge from Cape Coral Waterways into Matlacha Pass Aquatic Preserve*

Citation: DER Contract No. CM-230 Final Report.

Purpose: Water quality monitoring, investigating cattail invasion of the mangrove ecosystem, and vegetational and fisheries surveys of seagrass beds.

Geographic extent: Matlacha Pass, Pine Island Sound, and one site (MS-GK) at the intersection of Matlacha Pass, Caloosahatchee River, and San Carlos Bay.

Groups covered: Benthic vegetation (seagrass/seaweed) and fishes.

Sampling method: Benthic vegetation - Population and community structure data were collected at each site using 0.25 m^2 quadrats located randomly within the grass bed. Each quadrat was divided into four 0.0625 m^2 sections and one of these was randomly selected for sampling. For *Thalassia*, all shoots and blades were counted, and the lengths of 6-10 blades were recorded.

Fisheries surveys - Juvenile fish abundance in the seagrass study beds were assessed by seining. [Site MS-GK was] sampled from March 1989 to November 1989 [with a] beach seine with a mesh size of 0.25 inches… to capture juveniles as small as 10 mm. Before seining, the grass bed was visually surveyed by snorkeling to determine its outer margins. Two people standing 8 m apart pulled the seine a marked distance of 20 or 25 m; thus, each seine covered an area of either 160 or 200 m^2. Six to eight replicate tows were performed at each site, with each tow covering a different undisturbed area. Sampling was conducted within two hours of high tide. Fish captured were identified, enumerated, and measured on site.

Gear: Fish surveys - beach seine with a mesh size of 0.25 in.

Spatial scale: See Geographic extent. Benthic vegetation - 0.0625 m^2, fish surveys - 160 or 200 m^2.

Temporal scale: Benthic vegetation: December 1988, March, June, and September-October 1989. Fishes: bimonthly, March-November 1989.

Associated data: Water quality: temperature, salinity, conductivity, DO, turbidity, pH, ammonia, nitrate/nitrite, total Kjeldahl nitrogen, total phosphorus, orthophosphate, Chlorophyll (total, *a*), bacteria.

Conclusions: Benthic vegetation - Salinity is an important factor affecting seagrass and seaweed distribution, abundance, and seasonality in Matlacha Pass. It is difficult to assess the effect of freshwater or low salinity on seagrass and seaweed distribution and abundance because there are insufficient data previous to this study.

Fisheries - We could not conclusively determine if reduced salinity had a negative impact on fish abundance in nearshore seagrass beds. Many factors, in addition to salinity, can influence the abundance of juvenile fish in seagrass beds.

Summary: The conclusions noted above give an adequate summary of the article. The purpose of the work was to assess the effects of freshwater “leakage” into the Aquatic Preserve, but the lack of previous data limited the study to a description of “baseline” data in 1988-89. Only site MS-GK falls within the area of concern for the VEC study.

Author: Taylor, John L.

Date: 1974

Title: The Charlotte Harbor Estuarine System

Citation: *Florida Scientist* 37(4): 205-216.

Purpose: Description of estuarine system.

Geographic extent: Charlotte Harbor, Gasparilla Sound, Peace, Myakka and Caloosahatchee rivers, Pine Island Sound, San Carlos Bay.

Groups covered: Geology and Sediments, tide and currents, climate, tributaries, physical and chemical parameters, emergent vegetation, submerged vegetation, plankton, invertebrates and invertebrate fisheries, fishes and sport and commercial fisheries, amphibians, reptiles, birds, and mammals.

Sampling method: N/A

Gear: N/A

Spatial scale: N/A

Temporal scale: N/A

Associated data: Summary of water chemistry parameters.

Conclusions: None made.

Summary: This is a good summary of the various groups covered for the entire estuarine system. The information is greatly summarized. For the Caloosahatchee system, the article relies heavily upon the previous works by Gunter and Hall (1965) and Phillips and Springer (1960).

ACKNOWLEDGMENTS

Numerous individuals assisted us in locating and procuring literature upon which this study was based, and to them we are grateful. We especially thank Melinda Coffee and Wendy Allex at the FGCU library under the supervision of Carolyn Grey. We also thank Dave Moldal at the Charlotte Harbor National Estuarine Research Program and Margaret Bishop, Dick Dawdy, Cynthia Poekleman, and Jacque Rippe from the SFWMD.

Appendix – An alphabetized listing of the articles related to the environmental components associated with the Caloosahatchee River/Estuary and neighboring areas. This list includes references identified to date (21 March 1998) by the staff at FGCU. Those articles annotated for this evaluation are indicated by an asterisk.

Appendix F
ANALYSIS OF WATER AND NUTRIENT BUDGETS FOR THE CALOOSAHATCHEE BASIN VERIFICATION OF SUBBASIN BOUNDARIES

E.G. Flaig, P. Srivastava, and J.C. Capece
South Florida Water Management District
Department of Agricultural and Biological Engineering University of Florida

SUMMARY

Subbasin boundaries were developed based on previous basin studies and evaluation of the drainage network for the basin. A drainage network was developed for the Caloosahatchee Estuary Basin that located the flow paths for runoff. The drainage network was used to determine subbasin boundaries. These boundaries were compared to those delineated in the previous studies. The boundaries were verified using aerial photography, discussions with field engineers and, where possible, field visits. The revised boundaries are very similar to the previous ones. Small changes occur where recent urban and agricultural development have modified the drainage patterns. The uncertainty in the subbasin boundary coverage ranges from approximately 10 feet for boundaries near roads and other major structures to 500 feet in areas of diffuse sheetflow.

INTRODUCTION

One goal of the *Caloosahatchee Water Management Plan* (CWMP) is to develop a water resources management plan for the Caloosahatchee Basin. The management plan will address water supply requirements and the volume and timing of runoff. A critical issue will be the effect of alternative land and water management practices on water use and runoff. The impact of alternative management practices can be evaluated for the entire basin. However, the land use and water use characteristics of the basin are spatially heterogeneous and various alternatives will have different effects depending on location within the basin. These differences are due to differences in soils, drainage, and landscape. As such, it is necessary to evaluate water use and runoff for several tributaries of the Caloosahatchee River and Estuary. The basin can be divided into subbasins for evaluation of land management practices and monitoring discharge.

In this report, the current subbasin boundaries were reviewed and modified, as necessary, based on review of the hydrography and discussions with District staff. This report includes a modified subbasin boundary coverage, a description of the modification process, and a coverage indicating the differences between the original coverage and the modified coverage.

PRIMARY BASIN BOUNDARIES

The Caloosahatchee Basin can be delineated into several primary basins (**Figure F-1**). The primary basins are the East Caloosahatchee, defined as the land that drains into the C-43 Canal between Lake Okeechobee and the Ortona Lock and Spillway (S-78); the West Caloosahatchee, defined as the land that drains into the C-43 Canal between the Ortona Lock and Spillway and the Franklin Lock and Dam (S-79); Telegraph Cypress Swamp; Orange River; and the Caloosahatchee Estuary, defined as the land that drains to the Caloosahatchee Estuary downstream of Franklin Lock. The Caloosahatchee Estuary Basin can be divided into a tidal portion where tributary stage is affected by the tides, and the estuary portion that is upstream. The primary basin boundaries are the official SFWMD boundaries. These boundaries were developed by the U.S. Army Corps of Engineers (USACE) as part of the engineering analysis for the C-43 Canal design. The boundaries predate many changes in the local drainage.

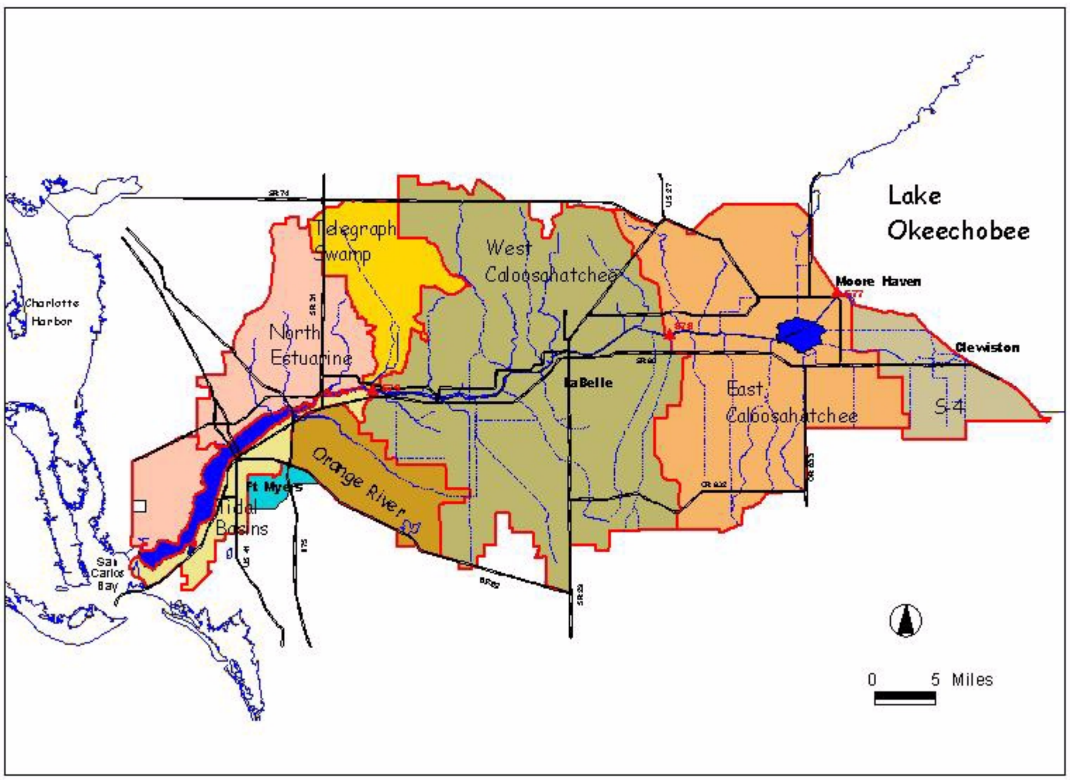

Figure F-1. Primary Drainage Basins of the Caloosahatchee Basin.

There are several locations where ambiguous or bidirectional drainage affects the Caloosahatchee Basin boundaries (**Figure F-2**). In these areas, the direction of storm water drainage is determined by antecedent water levels, runoff volume, and location of man-made structures. In general, baseflow drainage follows the basin boundaries defined in **Figure F-1**. However, at high water levels or following large storm events, the drainage pattern in these areas are subject to change. For example, a portion of the S-4

Basin (also known as the C-21 and S-235 Basin) may drain into the Caloosahatchee River. Drainage water from the C-21 Canal is released into the Caloosahatchee River through S-235 when the lake stage is greater than 15.5 feet or the stage exceeds the lake regulation schedule. The runoff is generated primarily from the Disston Water Control District (DWCD). Stormwater runoff from DWCD may be discharged through the S-4 or S-235 structures or may be discharged into the C-43 Canal through a private drainage pump or discharged to Lake Hicpochee through private drainage pumps.

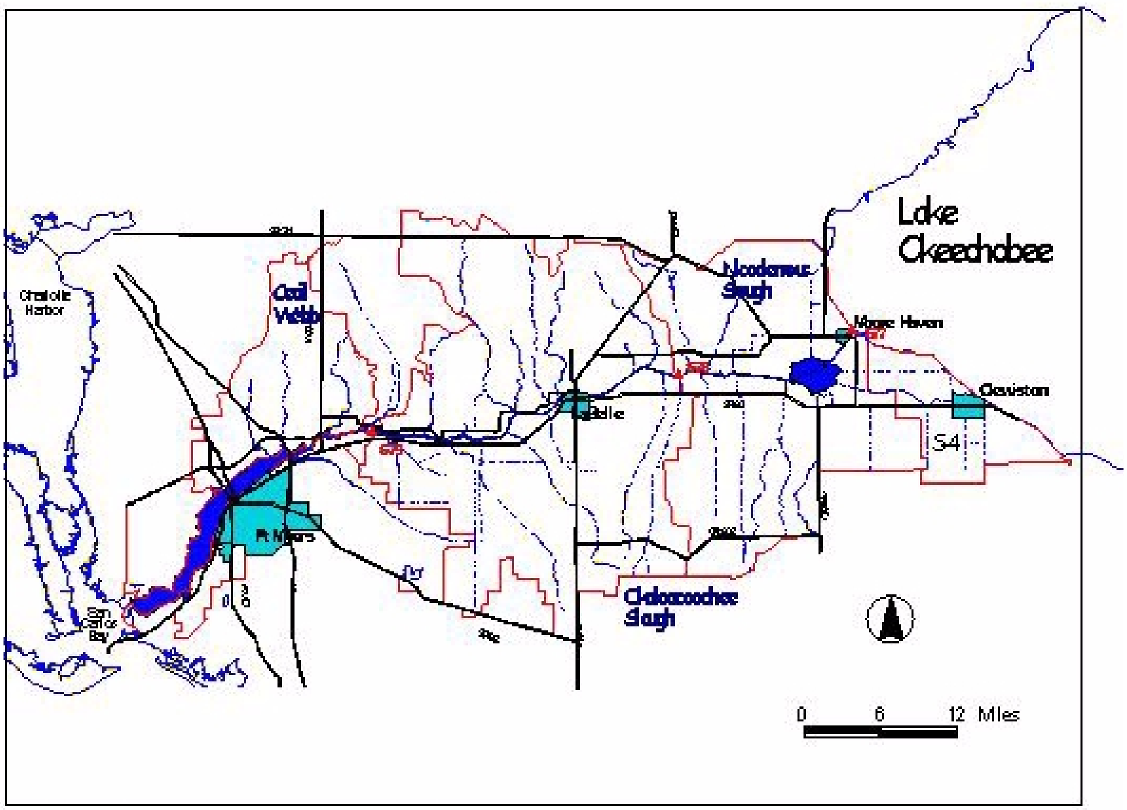

Figure F-2. Regions of Ambiguous or Bidirectional Drainage.

The Caloosahatchee River also captures drainage from Nicodemous Slough when Lake Okeechobee stage is high or runoff exceeds the conveyance capacity of the L-19 and L-21 borrow canals. Drainage water is discharged through the C-19 Canal into Lake Hicpochee. Under normal conditions, Nicodemus Slough drains to Lake Okeechobee.

The Caloosahatchee River may capture runoff from other basins due the variable nature of the basin boundary. Although the boundaries are generally well defined, there are two locations (the Okaloacoochee Slough and Cecil Webb Wildlife Management Area) where the basin is poorly defined. The headwaters of the Okaloacoochee Slough occur along the south edge of the basin. This area is very poorly drained with a mixture of marsh and swamp habitats. The area can drain northward into the Caloosahatchee River or southward into Fatahatchee Strand. The direction of flow may be dependent on down stream conditions of vegetative growth in the flow paths and antecedent water levels.

Review of historical maps does not clarify the drainage pattern. Older maps following available one-foot contour topography establish the basin boundary in different locations (Task 4 Report). A canal was constructed from SR 832 northward providing a flow path for drainage originating south of the road. This establishes the basin boundary south of the road during normal conditions. The exact location is uncertain.

The direction of drainage from the Cecil Webb Wildlife Management Area also depends on the antecedent water conditions of the area. The drainage from this area is split: it flows south to the Caloosahatchee and west to Matlacha Pass. With urban development, canals have been dug inland from Matlacha Pass to reduce flooding due to overland sheetflow from the Cecil Webb Wildlife Management Area. However, construction of a high-voltage transmission line and accompanying access road from Punta Gorda southeastward through the Cecil Webb Wildlife Management Area has altered the westward flow paths. Under low flow conditions, overland sheetflow runoff can drain through culverts in the access road to the west. Under high water level the access road diverts flow to the southeast. This results in a variable basin boundary affected by rainfall volume and antecedent water levels.

Each of these primary basins contain several tributaries. There are large tributaries defined by native streams, sloughs and canals. There are many small tributaries that drain small areas adjacent to the C-43 Canal. There also are several small tributaries that drain directly to the estuary.

BASIN HYDROLOGY

The subbasin boundaries are based primarily on the basin hydrography. Although topography is usually the most important factor affecting subbasin boundaries, the natural drainage patterns have been substantially altered by ditches. There are few areas in the basin where the natural drainage has not been changed.

The Hendry County portion of the basin has been extensively drained for agriculture. Five large canals were dug to eliminate the extensive inundation experienced during the 1950s (USACE, 1957). There are several smaller canals that provide additional drainage near LaBelle. Although individual groves have pumped drainage, the regional drainage system is primarily gravity-driven. The eastern end of the basin, east of Lake Hicpochee, is a large wet prairie area that was historically a sawgrass marsh with very poor drainage. Much of this area is characterized by muck soil. This region has been systematically ditched to provide drainage. The configuration of the canal system and discharge structures determines the direction of drainage. Much of the area has pumped drainage.

The Lee County portion of the basin has been ditched to provide drainage for urban development. Several ditches have been constructed that drain directly to the estuary. On the south side of the estuary, flow in these subbasins is controlled by many weirs and culverts. The eastern extent of the estuarine drainage is bounded by Six-Mile Slough and Cow Slough.

On the north side of the estuary in Lee County, the drainage pattern is controlled by native streams and man-made obstructions and ditches. At the west end of the basin, drainage is controlled by a series of ditches and structures in Cape Coral that were designed to retain freshwater and reduce saltwater intrusion. East of Cape Coral, the native drainage patterns were characterized by overland sheetflow in the higher elevations of Charlotte County that drained through several small streams to the estuary. Drainage from this area is now accelerated by ditches that drain from Charlotte County to the estuary. The result has been to increase the discharge and produce serious flooding.

SUBBASIN HYDROLOGY

The subbasin boundaries are defined by the subbasin hydrology which is controlled by landscape relief, native flow paths, and man-made structures. The native relief forms a shallow east-west valley between the Immokalee Island on the southern edge of the basin and a high point near Whidden Ranch on the northern extent of the basin. Although there is a natural north-south gradient with drainage toward the river, there are many areas in the basin that are essentially flat with little native drainage (**Figure F-3**). The drainage from these areas can be redirected by slight changes in elevation caused by shallow ditches or roads. In several locations, the result has been a redirection of flow to an adjacent creek producing localized flooding. Throughout the basin, there are locations were the east-west gradient is small and relatively minor changes in land elevation may redirect runoff into adjacent tributaries.

The subbasin boundaries may change as a result of urban or agricultural development. Drainage improvements such as berms and ditches have modified both local drainage and disrupted upstream flow patterns. Disruption of flow paths may be direct; diverting drainage to protect a new development, or subtle; constraining flow that once covered wide marsh into a narrow, eroding stream. This has been a common situation near major roads (SR 78, SR 80, and SR 29). It also has occurred in the North Estuary Basin. Each new improvement has the potential to modify the subbasin boundaries.

The drainage network was established by reviewing the native hydrography, wetlands, and man-made hydrography. It was expected that the published hydrography would be sufficient to define the drainage network. Unfortunately, the 1988 hydrography coverage does not contain sufficient information to establish the flow network in the basin. It was necessary to develop a more detailed drainage network based on reviewing the 1994-95 infrared aerial photography. As described in Task 4, all discernible flow paths that drained substantial areas were identified and included with the current hydrography. The process of identifying and defining the flow paths resulted in development of drainage network.

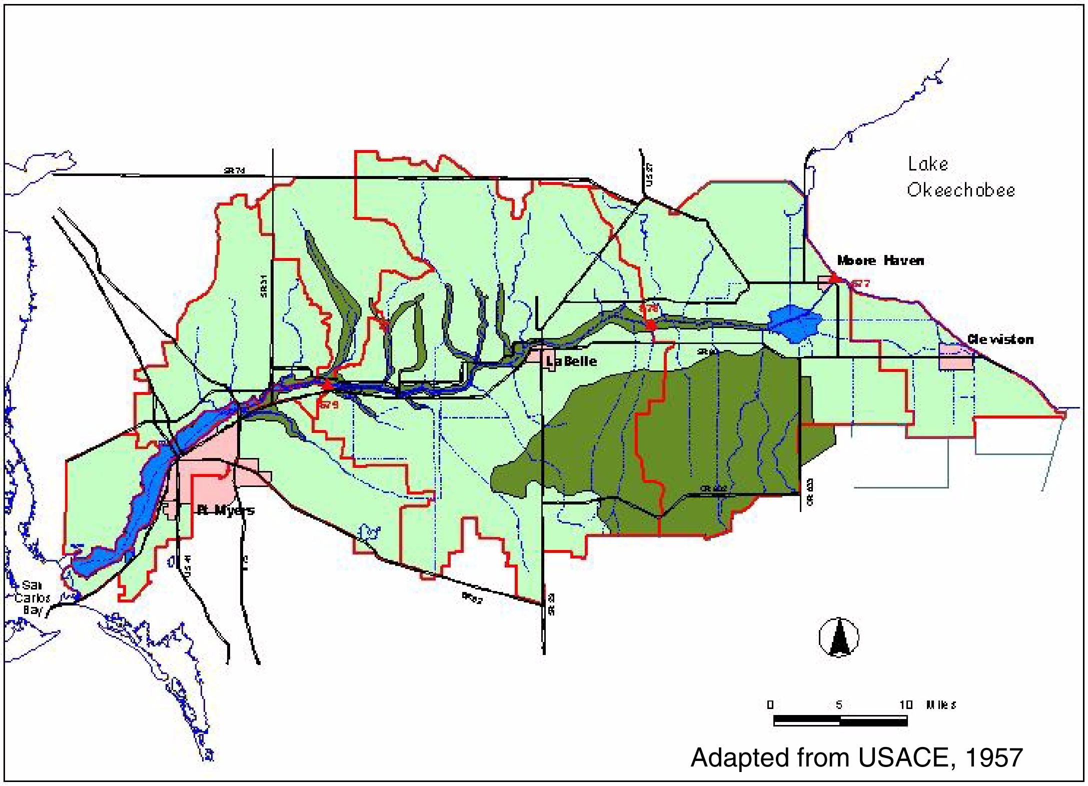

Figure F-3. Areas of Prolonged Flooding during 1948, 1951, and 1953.

SUBBASIN BOUNDARIES

A set of subbasin boundaries have been developed for the combined East and West Caloosahatchee Basins (CDM, 1994), Cape Coral (USGS, 1991), Lehigh Acres (ATM, 1995), and Lee County (Johnson Eng., 1992). CDM subbasins were developed to define the catchment for each of the significant tributaries. The CDM subbasin boundaries were based on tributary boundaries developed by Miller et al. (1982). Inflows to the Caloosahatchee east of LaBelle are regulated by culverts and pumps on the C-43 Canal. The culverts, part of the Central and South Florida Flood Control Project, are maintained by the U.S. Army Corps of Engineers (USACE). West of LaBelle the tributaries are primarily free-flowing inflows. A detailed description of these inflows was provided by CDM (1994). There are 147 inflows to the Caloosahatchee River between S-77 and S-79. However, many of these inflows drain small areas immediately adjacent to the canal and do not constitute individual subbasins. Forty-two subbasins were delineated (**Figure F-4**). The boundaries for these subbasins were developed by CDM based on site visits, review of engineering project reports, and interpretation of aerial photography.

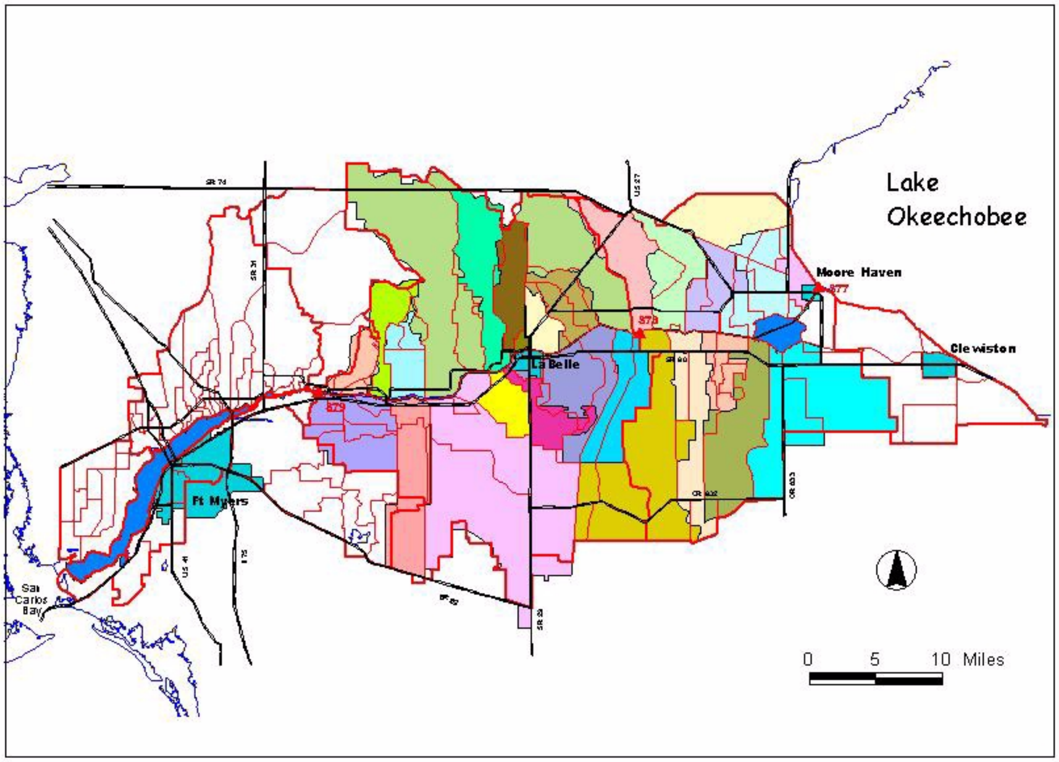

Figure F-4. Subbasins for the East and West Caloosahatchee Basins (CDM, 1994).

The subbasin boundaries for Lee County were developed by Johnson Engineering, Inc. (Johnson Engineering, 1992). They determine the boundaries and principle flow paths for 29 subbasins that drain to the Caloosahatchee River and Estuary (**Figure F-5**). These subbasins were identified as part of the Lee County Stormwater Management Master Plan. The Johnson Engineering, Inc. project did not include the cities of Fort Myers and Cape Coral. The basin boundaries for Fort Myers were determined from aerial photography. The subbasin boundaries for Cape Coral were described by the USGS (1991). The subbasin boundaries for Lehigh Acres were adapted from drainage studies conducted for East County Water Control District during the 1990s (A.J. Quattrone, personal communication, 1998). Similar to CDM, the Johnson Engineering study identified several small drainage areas along the estuary that were not considered subbasins and were lumped into a region of small estuary inflows. Because the Johnson Engineering study was restricted to Lee County, the northern extent of these subbasins in Charlotte County were not completed. These subbasin boundaries were extended by examining 1994-95 infrared aerial photography. Subbasin boundaries for southeastern Telegraph Swamp and northeastern Lee County were modified based on information from the Four Corners study (Smith, 1996).

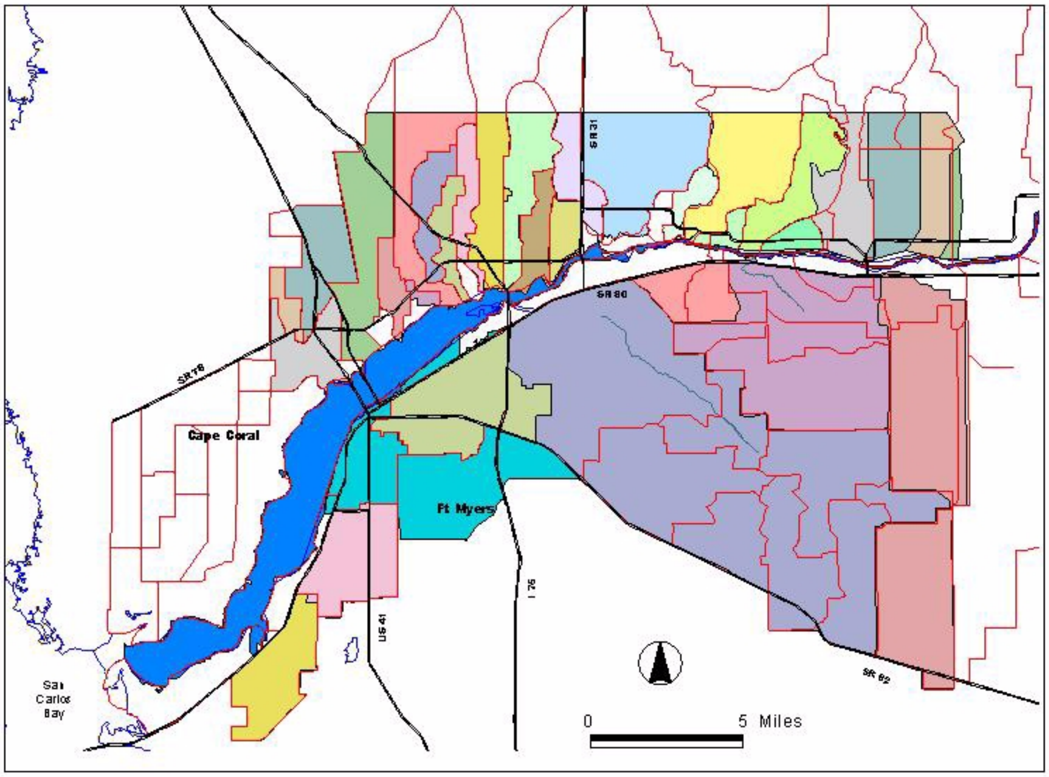

Figure F-5. Subbasins for Lee County (Johnson Engineering, 1992).

VERIFICATION OF SUBBASIN BOUNDARIES

The subbasin boundaries were verified using aerial infrared photography, discussions with SFWMD field engineers, and review of surface water permits. The surface water permits indicated where subbasin boundaries have been changed following the construction of ditches and berms. These changes were confirmed during discussions with field engineers. The engineers also indicated where boundaries were indeterminate due to lack of gradient or the result of flow controls on adjacent land that were set to discharge at different elevations. The discharge from these structures would change the direction of flow by imposing a new water head condition on the landscape. The new boundaries were checked against the previously established boundaries. Where differences occurred, a field visit was conducted to review the boundaries. In most cases field trips were possible. For locations where field access was not possible, the boundaries were reviewed using aerial photography.

The subbasin boundaries were verified independently using aerial photography. The aerial photography was used to determine the drainage network (Task 4). The drainage network was developed by tracing the flow path from the Caloosahatchee River to the headwaters. The flow paths were extended from well-defined paths such as streams and ditches to poorly-defined paths such as partially connected wetlands. The poorly-defined flow paths were confirmed by reviewing soil maps and topography. The drainage flow paths were extended to the edge of each subbasin to determine the boundary between adjacent subbasins. Where the flow paths could not be extended to meet the adjacent subbasin flow path network, the boundaries were considered indeterminate and the boundaries were drawn midway between adjacent flow networks.

The boundaries developed using the aerial photography were compared to the boundaries developed from the permit review. Where discrepancies existed, the aerial photographs and GIS soils, wetlands, and topographic coverages were reviewed, and using all of these resources together to identify probable flow paths and flow restrictions, the subbasin boundaries were delineated (**Figure F-6**). The subbasin boundaries for urban Lee County were not checked by field visits. It was felt that there were few changes in the landscape since the Johnson Engineering study was completed and the reported subbasin boundaries were reasonable.

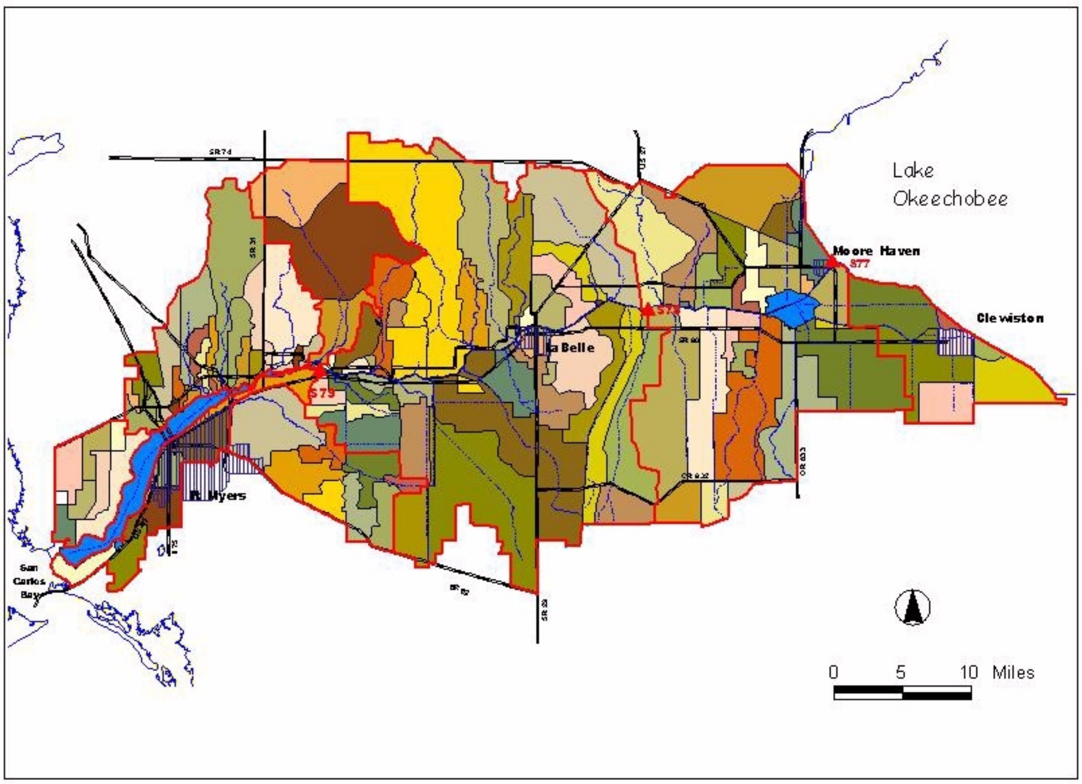

Figure F-6. Modified Subbasins for the Caloosahatchee Basin.

As indicated in **Figure F-7**, there are minor differences in the subbasin boundaries. The differences occur along the northern extent of the basin, Hendry County and the four counties area. The differences along the northern boundary result from changes in land use and additional refinement of the drainage flow path network. The differences in the subbasin boundaries in western Hendry County result from changes in land use as well as more detailed evaluation of local drainage patterns. The drainage subbasin boundaries in the four-corners region (where all four counties meet) have been carefully examined following flooding problems in that area. Although there remain some discrepancies in the boundaries, they have been changed to reflect the most recent information.

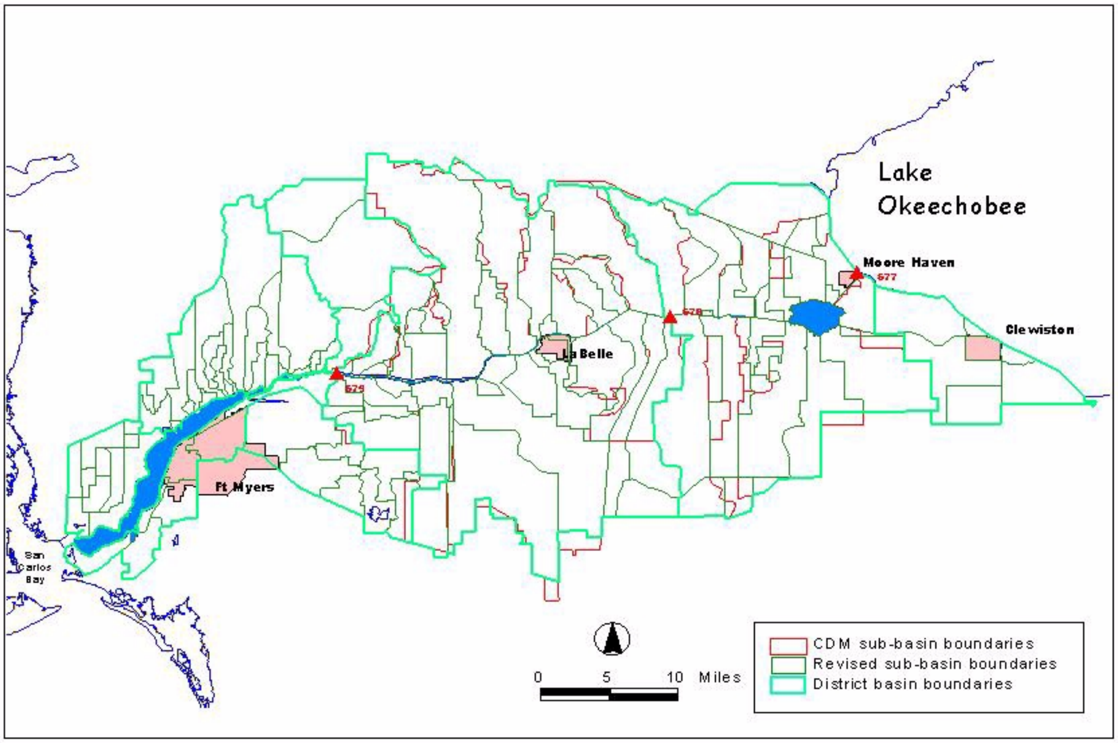

Figure F-7. Revised Subbasin Boundaries with SFWMD Drainage Basins and CDM Subbasin Boundaries.

The subbasin boundaries are subject to errors resulting from ambiguity in landscape drainage and errors due to the inaccuracies of the GIS coverages. The ambiguity in flow patterns occurring as a result of multiple drainage paths and level terrain produce an uncertainty in boundary location that can be as great as 200 feet. Where the boundary follows a berm or road, the probable error in the boundary location is 10-20 feet. In creating the subbasin boundary coverage, there is uncertainty due to the resolution of the maps and aerial photographs used to locate the boundaries. These sources of uncertainty are in the range of 10-20 feet and it is not possible to locate any boundary on these coverages with greater precision.

REFERENCES

Applied Technology and Management. 1995. Drainage Analysis of East County Water Control District. Unpublished engineering analysis. Applied Technology and Management. Lehigh, FL.

Camp Dresser & McKee. 1994. Caloosahatchee River Basin Assessment. Phase II: Water Quality Data Analysis Report. Report to South Florida Water Management District. Camp Dresser & McKee, Inc. Maitland, FL.

Johnson, Engineering. 1992. Lee County Storm Water Management Master Plan. Report to Lee County Board of County Commissioners. Johnson Engineering, Inc., Ft. Myers, FL.

Miller, T.H., A.C. Federico, and J.F. Milleson. 1982. *A Survey of Water Quality Characteristics and Chlorophyll a Concentrations in the Caloosahatchee River System, Florida*. Technical Publication 82-4. South Florida Water Management District, West Palm Beach, FL.

U.S. Army Corps of Engineers. 1957. *Central and Southern Florida Project for Flood Control and Other Purposes*. Part IV Supplement 6-General Design Memorandum, Caloosahatchee River and Control Structures. USACE, Jacksonville, FL.

U.S. Geological Survey. 1991. *Simulation of the Effects of Proposed Tide Gates on Circulation, Flushing, and Water Quality in Residential Canals, Cape Coral, Florida*. USGS Open-File Report 91-237. Tallahassee, FL.

The coverages described in this report are available on the anonymous ftp site at the Southwest Florida Research and Education Center: ftp:icon.imok.ufl.edu/pub/wqgis.